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Relationships of Transportation and Land Use, Economic Development, and Intercity Bus Issues

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Transportation Research Record 1125

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Contents

Foreword

This Record contains papers on the interrelationships among transportation, land use, and economic development. It also contains papers that deal with changes in intercity bus service and technological innovation.

Eyerly, Twark, and Downing describe the economic changes that occurred from 1970 to 1980 in communities adjacent to nonurban interchanges on the Interstate highway system in Pennsylvania. Many communities close to such interchanges have experienced growth in residential, commercial, and industrial activities.

Henry Moon reports on a study of 65 nonmetropolitan interchanges in Kentucky. Six of the interchanges have developed into "interchange villages" that serve as regional centers, tourist-driven service centers, and island communities of other urban places.

Zemotel, Bullen, and Hummon focus on the relationship between transportation services and the needs of advanced-technology firms. Both methodological and substantive issues are discussed.

For the past three decades, while transit ridership in the United States has been declining, Europe has experienced a steady or increased use of public transport. Webster and Bly, in their paper on changing patterns of urban travel, assert that the private car will account for an increasing share of travel in noncentral urban areas and small towns. This decentralization of travel will also lead to a decline in transit usage.

In their second paper, Webster and Bly state that public transport will ultimately decline in Europe, even in those countries where its use is currently increasing. Dispersed suburbanization will continue to encourage the use of cars instead of public transport. This trend may be slowed by the use of ever increasing public transport subsidies.

Stephen Putman, in his paper on mathematical transportation and land use models, considers the practical application of recent research. The models discussed include linear programming, TOPAZ, and GAMS.

Tung and Schneider offer another transportation–land use model, the Urban Form Optimization System, that can support an interactive graphic design and evaluation process. Examples that illustrate its capabilities are provided.

The last three papers in this Record deal with intercity bus service.

New intercity bus technologies and their cost-efficiency in Canada are the subject of the paper by Nookala and Khan. Three new technologies for intercity buses are evaluated: an articulated bus, a rigid body double-deck bus, and an articulated double-deck bus.

College students are a major segment of the intercity bus market. The paper by Kuehne and Hollandsworth is a report on a survey of home locations of students at 26 Michigan universities. The objective of the study was to identify special weekend intercity bus service needs of college students.

Hansen and Beimborn examine the nature of and methods for estimating the benefits to users and nonusers of intercity bus services. A model that can be used to calculate a benefits index is presented.

Interstate Highway System: Reshaping the Nonurban Areas of Pennsylvania

RAYMOND W. EYERLY, RICHARD D. TWARK, AND ROGER H. DOWNING

In this study are described the economic changes that occurred from 1970 to 1980 in communities adjacent to selected nonurban interchanges on the Interstate highway system of Pennsylvania. These changes are compared with those in the counties in which the interchanges are located and in the state as a whole. Indices of economic growth, both conventional (i.e., housing, income, employment, population) and new (assessed market value of real property), are used. Changes in per capita income at the county level were found to be positively related to the existence of nonurban interchanges in the county. The economies of many nonurban communities near the Interstate system are continuing to be reshaped with large increases in residential, commercial, and industrial growth.

Conventional or traditional indices of economic growth (housing, income, employment, population) have been used in numerous studies of economic development resulting from transportation improvements. A major advantage of these indices has been their availability at low cost from secondary sources. Drawbacks to the data sets on which the indices are based have been the time lags between successive measurements (e.g., census data are collected every 10 years) and the unavailability of certain data sets on a local basis.

Real estate values can also be used as surrogates for changes in the economic climates of local communities. Many studies have avoided indices based on real estate data sets because of the high cost of collection of reliable market values from original sales data and the problems with extrapolation of values for properties that have not been on the market. Local taxing jurisdictions are, however, continually updating the data sets that are used for collection of taxes on real property. Recent changes in data collection and handling of assessment market values for real estate taxation purposes have provided possibilities for constructing new indices. Major advantages are that these indices are available on an annual basis, are becoming increasingly reliable for many taxing jurisdictions, are available on a local area basis, and can be broken down by land use classes.

In this study, the traditional and the new indices will be applied to analyze the possible economic reshaping of nonurban areas in Pennsylvania by the Interstate highway system.

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BACKGROUND

The Interstate highway system, authorized by the Federal Highway Act of 1956, contains approximately 42,500 mi of limited-access highways. There is no doubt that the Interstate system has reshaped the economic topography of the United States *(1)*. Although the system was designed to connect the metropolitan centers of the United States, much of the system is located in rural or nonurban areas. Many of these areas were not formerly served by major highways or other intercity transportation systems.

Because of the size of the undertaking (i.e., building a highway system that altered local, regional, and national transportation patterns), it could be expected that it would have significant effects on the economic and social settings of communities along the highway corridors. These effects would probably be more apparent in communities containing interchanges between the Interstate system and the local transportation system.

While the Interstate system was under construction, a portion of the monies designated for the program was devoted to research on the social and economic effects of Interstates on local communities. Because much of this research was conducted while the highways were being constructed or shortly thereafter, these studies were essentially predictive in nature *(2,3)*. Early studies could only give inklings of the types of development that might occur in areas adjacent to Interstate highways. What actually happened can be determined only from a historical perspective.

The main focus of earlier research was to determine the types and levels of highway-oriented and other commercial, residential, and industrial developments that would likely occur in interchange communities. This information was useful to government officials and planners seeking to stimulate orderly growth, to maintain the safety and adequacy of local highways, and to create desirable overall community environments.

Most earlier studies included such variables as population, employment, household income, and housing *(4,5)*. In recent years additional measures of growth have become available. These include newer and better annual measures of income and, as mentioned earlier, of real estate market values. In the case of market values of real estate, the amount and value of income-producing properties such as industrial, commercial, and residential properties are now fairly easy to obtain from most taxing jurisdictions. Thus, with more and better information available coupled with the maturing of the Interstate system, it is possible to provide from a historical perspective a more accurate description of types and levels of economic developments in communities containing Interstate interchanges versus other communities.

SELECTION OF STUDY AREAS

Continuing studies of interchange community development have been conducted by Twark and Eyerly since the early 1960s *(6,7)*. They have had under observation 164 selected nonurban interchanges in Pennsylvania since these interchanges were opened to traffic. The highways studied were I-70, I-78, I-79, I-80, I-81, I-83, I-90, and I-176. When these interchanges were selected, a criterion was that the communities surrounding the Interstate interchange have little or no prior economic development other than traditional rural activities such as farming, forestry, mining, and the like. These interchanges were located in portions of 182 minor civil divisions (MCDs) and 32 counties.

Data have been maintained over time on all types of development within a radius of 1/2 mi of each interchange. The data bank also included distance to nearest urban area; average daily traffic on the Interstate and the cross route; and the population, area, and market value of real estate in the local community, the county, and the nearest urban area. In 1980 a model to estimate economic growth at nonurban, limited-access highway interchanges was published *(2)*. This model was applicable to the study and simulation of the impacts of various interchange sites before the final location and design of a specific interchange. It could also be used in the redesign of obsolete interchanges.

This paper will provide a brief description of the growth and change that occurred in municipalities in which the nonurban interchanges are located. The data bank for the 164 nonurban interchanges is used, but additional data, which are more recent and broader in geographic context, will also be analyzed.

PROCEDURE

Indices of local economic growth will be compared with county and state growth indices. The county and state indices include information from all MCDs within their boundaries and do not exclude the MCDs containing nonurban interchanges. The indices of economic growth will show the percentage changes in population, housing, employment, income, and assessed market value of selected land use categories. Statistics on population, housing, and area in square miles are given in Table 1. The indices are constructed from population, housing, and employment data provided by the Bureau of the Census;

TABLE 1 SELECTED 1980 STATISTICS FOR THE STATE, NONURBAN INTERSTATE INTERCHANGE COUNTIES, AND LOCAL COMMUNITIES

		Non-Urban Interstate Interchange Areas	
	State (67 Counties)	32 Counties	182 Local Communities (MCD's)
Population	11,863,895	4,626,026	658,433
% of State	100	39	5.5
% of County		100	14.2
Area in Sq. Miles	44,888	21,204	3,616
% of State	100	47	8.1
% of County		100	17.1
Total Housing Units	4,596,431	1,793,600	249,913
% of State	100	39	5.4
% of County		100	13.9

income data obtained from census data and the Department of the Treasury; general revenue-sharing data for the fifth and fifteenth entitlement periods; and assessed market value data and real estate sales data from the Pennsylvania State Tax Equalization Board. The latter sets showed the assessed market values and sales data for seven land use classes (residential, lots, industrial, commercial, farms, vacant land, and minerals) for each MCD and county in Pennsylvania. These indices of land use change were previously used to measure community growth around nuclear power plants *(8)* and for second-class townships in Pennsylvania *(9)*. See Table 2 for more detailed information.

It was thought that it would be worthwhile to further examine, using multiple linear regression, the effect on per capita income that the Interstate system has in counties through which it passes. Variables included those used for the indices as well as others that could be used to explain percentage changes in per capita income.

RESULTS

Table 3 gives the economic indices for the period 1970 to 1980 for the state and for 32 counties and 182 MCDs with nonurban Interstate interchanges. From this table it can be seen that the population growth of Pennsylvania has been minimal, 0.5 percent. The counties that contain nonurban interchanges grew at the rate of 6 percent. The interchange MCDs or local communities grew 22 percent. There was a substantial population increase in the interchange communities compared with the counties in which they were located and with the state as a whole.

The state had a 17 percent increase in housing units. Nonurban interchange counties had a 22 percent increase, but the nonurban interchange MCDs grew at nearly twice the county rate with a 43 percent increase in housing units. Analogous to the growth in housing units is the increase in assessed market value of residential property. These residential value indices,

TABLE 2 INDICES OF ECONOMIC GROWTH: DESCRIPTION AND SOURCE OF INFORMATION

Economic Index (In Percent)	Description
Population:	Change in population from 1970 to 1980 for the state and non-urban interstate interchange counties and local communities. These communities are the minor civil divisions (MCD's) of Pennsylvania, i.e. boroughs, townships or cities. Source: U.S. Bureau of the Census.
Housing:	Change in the number of housing units from 1970 to 1980. Source: U.S. Bureau of the Census.
Income:	Per capita change in income from 1970 to 1980. This measure is derived from the 1970 and 1980 U.S. Bureau of the Census Report for the MCD's of Pennsylvania. The Treasury Department's revenue sharing data for the 5th and 15th entitlement period is used.
Employment:	Change in the local work force from 1970 to 1980. Source: U.S. Bureau of the Census (not available for MCD's).

TABLE 2 *continued*

Economic Index (In Percent)	Description
Residential:	Change in residential real assessed market value derived from locally assessed values 1970-1980, adjusted for differences between counties and also for inflation. Source: Pennsylvania State Tax Equalization Board (STEB) and The Economic Report of the President.
Commercial:	Change in commercial real assessed market value (same adjustments and sources as in residential).
Industrial:	Change in industrial real assessed market value (same adjustments and sources as in residential).
All Developments:	Change in the real assessed market value for all land use classes: residential, commercial, industrial, lots, farms, vacant land and minerals (same adjustments and sources as in residential).

adjusted for inflation, went up 30 percent at the state level, 35 percent at the county level, and 52 percent at the MCD level.

The housing indices in conjunction with the population indices reflect the national pattern of a changing life-style in which there are more housing units and fewer persons per household. The growth revealed by these indices would indicate a possible preference for living in MCDs with access to the Interstate for work, shopping, and recreational trips.

Two other measures of growth are per capita income and employment. The employment indices grew 9 percent at the state level and 15 percent in counties with nonurban Interstate interchanges. Unfortunately, data do not exist for a comparison at the MCD level. Per capita income, adjusted for inflation, increased 16 percent at the state level, 23 percent at the county level, and 27 percent at the MCD level.

Other studies *(2, 10)* indicate that the most common form of development that occurs at nonurban interchanges during the first few years is highway-oriented enterprises. At later stages, other commercial enterprises, industries, and residential developments locate in areas near interchanges. The all-developments indices, which consisted of the assessed market values of all seven land use classes, increased 25 percent at the state level, 32 percent at the county level, and 56 percent at the MCD level as the data in Table 3 indicate.

Because the MCDs in this study are mainly rural and had a relatively low commercial base, any new commercial enterprises would probably be reflected in dramatic increases in the market value of commercial properties. At the state level there has been an 18 percent increase in the assessed market value of commercial properties. At the county level there was a 38 percent increase, whereas the nonurban MCDs with interchanges showed an 86 percent increase in the value of commercial properties.

One of the phenomena that have been taking place in the country has been a deterioration of the industrial base. Therefore it is not surprising to find that at the state level there has been only a 3 percent increase in the market value of industrial properties and at the county level a 6 percent increase. However, at the nonurban MCD level there was a 70 percent increase in the market value of industrial properties. Thus nonurban interchange communities have attracted commercial properties and industry such as light manufacturing facilities at growth rates that exceed those of the county and the state.

TABLE 3 PERCENTAGE CHANGES IN ECONOMIC INDICES FOR THE STATE, COUNTIES, AND LOCAL COMMUNITIES

Economic Indices	State (67 Counties) %	Non-Urban Interstate Interchange Areas: 32 Counties %	Non-Urban Interstate Interchange Areas: 182 Local Communities (MCD's) %
Population	0.5	6	22
Housing	17	22	43
Income	16	23	27
Employment	9	15	*
Residential	30	35	52
Commercial	18	38	86
Industrial	3	6	70
All Developments	25	32	56

*Employment data are not available at the MCD level.

TABLE 4 LIST OF INDEPENDENT VARIABLES CONSIDERED FOR A MULTIPLE LINEAR REGRESSION ANALYSIS TO EXPLAIN CHANGES IN PER CAPITA INCOME

Independent Variable	Description
INC	The county income per capita in 1970 adjusted by the gross national product to 1980 dollars.
COM	The proportion of the county tax base in commercial property in 1980.
IND	The proportion of the county tax base in industrial property in 1980.
AGRI	Proportion of the county tax base in agricultural property in 1980.
MIN	Proportion of the county tax base in mineral rights property in 1980.
COAL	A dummy (0-1) variable for a bituminous coal producing county.
INTCO	A dummy (0-1) variable for a county containing one or more non-urban interstate highway interchanges.

Eyerly, Downing, and Twark, in an earlier study *(11)*, found that per capita income had increased more between 1970 and 1980 in Pennsylvania bituminous coal mining counties than in nonmining counties. Much of that effect could be accounted for by the increased costs of energy during the 1970s and the concomitant effects on the economies of energy production areas.

A regression model employing mining-related variables coupled with the nonurban Interstate highway variables might better explain the increases in per capita income at the county level in Pennsylvania. The list of independent variables considered is given in Table 4. An equation using statistically significant variables is given in Table 5. From this table it can be seen that, in addition to the coal and mineral variables, the existence of an Interstate highway in the county is an important factor, as was earlier suggested by the economic indices. The industrial base and level of income were also significant factors.

TABLE 5 REGRESSION RESULTS FOR THE PERCENTAGE CHANGE IN COUNTY PER CAPITA INCOME, 1970–1980

	Regression	Student	Level of Significance		
Variance	Coefficient	"T"	10%	5%	1%
INC	-0.0078	-3.57			X
IND	43.39	1.75	X		
MIN	39.45	2.28		X	
COAL	6.32	3.36			X
INTCO	4.14	2.42		X	
CONSTANT	33.25	5.43		X	

R^2 = .479

"F" Ratio = 11.24

Number of Observations = All 67 Counties.

TABLE 6 PERCENTAGE CHANGES IN SELECTED ECONOMIC INDICES FOR THE STATE, COUNTIES, AND LOCAL COMMUNITIES, 1970–1984

		Non-Urban Interstate Interchange Areas	
Economic Indices	State (67 Counties) %	32 Counties %	182 Local Communities (MCD's) %
Residential	35	44	64
Commercial	21	44	95
Industrial	-13	9	90
All Developments	27	39	65

MORE RECENT COMPARISONS

One advantage in using the assessed market value data to measure local economic change is that this information is readily available and is updated every year by county assessment offices. This is in contrast to census data that are limited to 10-year time cycles leaving open to speculation the fluctuations of census indices between collection dates.

Table 6 gives the percentage changes in selected assessed market values of real estate indices for the state, county, and MCDs from 1970 to 1984. From this it can be seen that residential property value is continuing to increase but more so at the nonurban interchange MCDs than at the county or state levels. Commercial property values are continuing to grow in a similar manner. Industrial properties at the state level have, however, been reduced in value by 13 percent. Counties and MCDs with nonurban Interstate interchanges have continued to grow, 9 percent for the counties and 90 percent for the MCDs. This strongly suggests that new industrial growth is linked to the presence of an Interstate highway interchange in the community.

CONCLUDING REMARKS

The findings of this study substantiate the early hypothesis that the Interstate highway system would encourage growth in local communities. An advantage of this study is that the Interstate system has been in place long enough to provide documentation of the reshaping of the economic structures of many local communities. All indices examined provide evidence of strong growth, particularly industrial growth, at the nonurban interchange community level compared with the county and the state levels.

In addition to the traditional indices of economic growth such as population, income, housing, and employment, new indices were constructed and used. These indices are based on the assessed market value of real estate and can be obtained in some states on an annual basis for large and small communities or even parts of these communities. These new indices can have wide application in studies measuring community change.

The study reported here was conducted in Pennsylvania, which has strict legal requirements for disclosure of sales prices because of a realty transfer tax; statewide monitoring and collection of sales and assessment data by a State Tax Equalization Board (STEB), which is required by law to provide formula funding to school districts; and publication of STEB data and assessment-sales ratios. The assessment-sales ratios are required by a "Common Level of Assessment" law and can be used to test the reliability of the assessed market values in a county.

It is important for researchers to identify the sources and the reliability of sales price data and assessed market value data when working in other states. Assessment practices vary widely from state to state and within states. Reliability of sales data also varies because of differences in laws requiring disclosure of sales price of real estate. A recent study by Majchrowicz *(12)* provides insights on a state-by-state basis into the adequacy and quality of sales price data for estimating real estate market values.

As a further note, in many assessment jurisdictions, the assessment market value records contain location codes such as block and lot number, tax map and parcel number, and so forth. With location codes, the researcher can start with an individual property location and add additional properties to achieve any size or configuration of the research area. This procedure is more difficult without location codes but can be accomplished with extra effort on the part of the researcher. It is also extremely helpful to have access to computerized assessment records but they do not always exist.

REFERENCES

1. R. J. Samuelson. Highways to Everywhere. *Newsweek,* June 30, 1986, p. 50.
2. R. D. Twark, R. W. Eyerly, and R. B. Nassi. Quantitative Technique for Estimating Economic Growth at Nonurban, Limited-Access Highway Interchanges. In *Transportation Research Record 747,* TRB, National Research Council, Washington, D.C., 1980, pp. 12–19.
3. R. Briggs. Interstate Highway System and Development in Nonmetropolitan Areas. In *Transportation Research Record 812,* TRB, National Research Council, Washington, D.C., 1981, pp. 9–12.
4. C. R. Humphrey and R. R. Sell. The Impact of Controlled Access Highways on Population Growth in Pennsylvania Nonmetropolitan Communities, 1940–1970. *Rural Sociology,* Vol. 40, 1975, pp. 332–343.
5. D. T. Lichter and G. V. Fuguitt. Demographic Response to Transportation Innovation: The Case of the Interstate Highway. *Social Forces,* Vol. 52, No. 2, Dec. 1980, pp. 492–512.
6. R. D. Twark. A Predictive Model of Economic Development at Non-Urban Interchange Sites on Pennsylvania Interstate Highways. Ph.D. dissertation. Pennsylvania State University, University Park, 1967.
7. R. W. Eyerly. Economic Impacts of an Interstate Highway on Four Selected Pennsylvania Interchange Communities. Ph.D. dissertation. Pennsylvania State University, University Park, 1972.
8. H. B. Gamble, R. H. Downing, and O. H. Sauerlender. Community Growth Around Nuclear Power Plants. *Journal of American Real Estate and Urban Economics Association,* Vol. 8, No. 3, Fall 1980, pp. 268–280.
9. H. B. Gamble and R. H. Downing. The Relationship Between Population Growth and Real Assessed Market Values: Note. *Growth and Change,* Vol. 16, No. 3, July 1985, pp. 74–77.
10. R. W. Eyerly and R. D. Twark. A Study of the Effects of Highway Development Policy on Rural Communities. In *Applied Simulation and Modeling,* The International Association of Science and Technology for Development, Calgary, Alberta, Canada, 1985, pp. 181–185.
11. R. W. Eyerly, R. H. Downing, and R. D. Twark. Resurgence of the Coal Industry: Effects on Per Capita Income in Pennsylvania. *Proc., Pennsylvania Academy of Science,* Vol. 58, No. 2, 1984, pp. 209–212.
12. T. A. Majchrowicz. *Sales Data in the Property Tax System: Their Adequacy to Estimate Market Value.* ERS Staff Report AGES860314. Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture, April 1986, 15 pp.

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Interstate Highway Interchanges as Instigators of Nonmetropolitan Development

HENRY E. MOON, JR.

Although the Interstate highway system of the United States is the subject of much varied and detailed investigation, much of the inquiry performed to date suffers an inexplicable urban bias. This study focuses on the nonurban impact of the nation's premier transportation network by examining 65 nonmetropolitan interchanges in Kentucky. Six interchanges are identified as "interchange villages" that actually function as central places in their respective regions. Three of this subgroup that are stereotypical are analyzed as examples of the different functions that they perform. These newly formed towns serve as island communities of other urban places, tourism-driven service centers, or focus points of entire regions. The cyclic pattern of evolution that nonmetropolitan interchanges can be expected to follow is presented as well as a discussion of what might be in store for these previously remote and isolated interchange sites. This project fills a void in the literature because it provides an in-depth nonurban analysis based on a significantly large number of observations.

Since Congress funded construction of the Interstate and Defense Highway System in the mid-1950s, the system has significantly altered the transportation network of the United States. The impact, which has substantially modified traffic flow patterns, has also influenced land use in areas adjoining system routes. Thousands of acres of property have been removed from other uses by the structure of the highway itself, and even more land has been drawn into the realm of highway-related development by its newly acquired connection with previously distant places. The system's main purpose is to connect major metropolitan areas of the United States, but these connecting routes pass through nonmetropolitan areas lying between the nodal cities and provide the potential for direct, high-speed access to or through places that might have previously been remote and relatively inaccessible.

The type and intensity of the impact of Interstate highway construction can be expected to vary from one region to another and within regions depending on a variety of site and situational characteristics. These characteristics may be in situ (in place before construction) or a function of the highway itself. Among these characteristics are historical, social, economic, site-specific, population, and geographic variables that necessarily influence the form and function of the region's transportation network and its local impact. Along any given link of the Interstate system, access points or interchanges are likely to be places where this impact on local communities is greatest. Interchanges are specific points at which traffic can enter or exit the Interstate highway from or onto another artery of any type. Commercial businesses such as fast-food restaurants or gasoline stations that are dependent on large threshold populations may seek to locate at high traffic volume interchanges or at interchanges near cities and towns in order to capitalize on two distinct populations. Some businesses and industries are dependent on Interstate truck traffic as clients or as shippers to move their products or raw materials and may find interchange locations cost-effective. On the other hand, residents of remote areas may build homes near an interchange to improve their accessibility to commuting opportunities. Local and state governments may use interchange locations to provide easy access to agencies and services by county or regional populations. Because Interstate highways have limited access, a single interchange may be the accessibility focus for an area of hundreds of square miles. This research focuses on the clustering of land use activity observed at certain nonmetropolitan Interstate highway interchanges and attempts to establish the need for more investigation of these newly formed nodes. In addition, a theory that attributes this recent development to new central place formation is presented. Underlying the project's purpose are a theoretical neglect of the subject and the increasing need for in-depth North American inquiries by those dedicated to land use research in nonmetropolitan areas.

LITERATURE REVIEW

Although the main purpose of most transport arteries is to connect nodal or terminal cities or points, these connecting routes pass through nonmetropolitan areas lying between them and provide the potential for interregional interaction and regional change. Not the least of the potential changes experienced by transected nonmetropolitan areas is that of an altered land use pattern. Land use changes have been documented for nearly every form of transportation that has entered nonmetropolitan America. Goodrich et al. (*1*, 224–225) identified the nonurban implications of canal construction in the nineteenth century:

> Between the terminal points, the canal may, as the most efficient mode of transportation in the area through which it passes, stimulate local development through its power to attract economic activities that are heavily dependent upon external transport economies. The process may first begin with a concentration of commercial farming in the vicinity of the canal. If

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> this development is followed by significant increases in population density—as a result of migration both from within and outside of the area—a market basis for the establishment of nonagricultural activities will have been established. Villages or small towns, specializing in manufacturing operations, may follow. Such developments would cause property values in the vicinity of the canal to rise faster than in other areas, and this second increase in the real value of assets may act as a stimulant to local investment or to higher levels of consumer expenditures—effects that might well sustain a cumulative process of change within the area.

Railroads also influenced land use between larger, urban nodal points. Stilgoe (2, p. 3) writes of the railroad late in the nineteenth century:

> Reaching from the very hearts of great cities across industrial zones, suburbs, small towns, and into mountain wilderness, the metropolitan corridor objectified in its unprecedented arrangement of space and structure a wholly new lifestyle. Along it flowed the forces of modernization announcing the character of the twentieth century, and abutting it sprouted new clusters of building.

Stilgoe specifically addresses the significance of interchanges by referring to the "crossing-zone commercialism" occurring there. An attribute of this planned nonmetropolitan development was the "standardization" of the nonurban landscape. Additional influences were evident with the concentration of buildings and activity at an intersection as the most visible change—that involving a community's land use.

In the early twentieth century, interurban railways influenced nonmetropolitan areas between and around cities. These short-lived predecessors of the truck and automobile also resulted in rural land use change. The electric interurbans also concentrated their effect at nodes. In addition, Hilton and Due (1964) observed that "their [the interurban railroads'] principal influence was, clearly, in conditioning the rural population to a greatly increased mobility that was fully realized only with the general acceptance of the automobile" (*3*, p. 117). Although this mode of transportation was limited in its impact, it did generate the same propensity for land use change at stops along its routes as did larger transport facilities.

No mode of transportation has altered nonmetropolitan land use more than the automobile. From the advent of Henry Ford's family car to the implementation of high-speed, limited-access freeways, automobile transportation has continually reshaped urban and nonurban places. Again, intersections or interchanges are recognized as the points at which the impact of the artery is greatest. Erickson and Gentry refer to the concentrations of development at interchanges as "nucleations" *(4)*. Although their analysis is of an urban environment, the concept of highly concentrated spatial influence is applicable elsewhere. Perhaps nowhere is this concept more visible than at nonmetropolitan Interstate highway interchanges where thousands of automobiles daily come in contact with formerly isolated rural communities.

Interstate highway interchanges have been analyzed by a wide array of researchers and from an equally broad set of perspectives. Further examination of the literature reveals that a large majority of land use change studies were performed when the Interstate system was in its infancy. For example, Garrison studied the supply of and the demand for land at interchanges in 1961 *(5)*. He focused on the availability of property and a hypothetical need that might eventually come to be for it. He did not address specific potential uses for interchange property other than those generally associated with increasing urban growth. Another popular topic of the period was the planning aspect of interchange development. Walsh *(6)*, Flaherty *(7)*, and Thiel *(8)* wrote on the need for land use planning around interchanges. The utility of land near interchanges for specific purposes was also identified during the 1960s. Kiley *(9)* studied highways as one factor in industrial location, and Graybeal and Gifford *(10)* evaluated the impact of new uses on the value of land near interchanges. Kiley found nonmetropolitan highways to be critical albeit necessary elements in the decision to relocate an industrial facility to a nonurban place. Graybeal and Gifford modeled the increasing land values associated with new transport systems, further evidence of the local impact of highways. The commercial attractiveness of interchanges has been and continues to be a popular research topic among those interested in Interstate-induced change. Both Mason and Moore *(11)* and Kovacik *(12)* have identified Interstate highway interchanges as prime sites for commercial activity. Traffic generation and traffic pattern alteration have been studied by Babcock and Khasnabis *(13)* and by Deen *(14)*, respectively. The overwhelming conclusion of these studies is that change in an area's transportation system necessarily results in more and often widespread change. In addition to these examples of interchange analysis, researchers of the 1960s attempted with little success to model different aspects of Interstate highway influence using a variety of methods and modeling techniques.

Early on, Cribbins et al. *(15)* assessed the economic impact of Interstate routes on both land value and use. After studying five sections of highway totaling 57 mi, they concluded "that the controlled-access facilities under investigation have done little to stimulate or depress surrounding property values and development. . . ." Two economists, Ashley and Berard *(16)*, surveyed 66 interchanges along I-94 across Michigan to measure the "benefits" accruing at each site. They classified and analyzed each interchange according to location (urban, rural, etc.), type (full, partial, and closed), economic value, and number of real estate transactions generated. Findings revealed that interchange location and type influenced potential development. In concluding this qualitative analysis, the authors write (*16*, p. 58):

> A basic principle of real estate activity is change, and probably the most dynamic example of this principle is found in the interchange area.
>
> The limited-access freeway has broken the mold of the old highway commercial pattern. It concentrates development rather than diffuses it and, consequently, allows investment in more lavish improvements. It has given a permanency to investments that never existed before in the history of highways.

Their findings further illustrate the importance and influence of interchanges, particularly those located in areas that are easily changed. The writings of Ashley and Berard substantiate the need for further work as they emphasize the unique and innate ability that interchanges have for generating change.

Twark *(17)* attempted to model economic development at 100 nonurban interchange sites on Pennsylvania Interstate highways. He developed three models of a static nature to describe the "equilibrium state" of economic development in the "neighborhood" of a given interchange. Twark measured traffic volume, local topography, interchange age, and distance to the nearest urban center as independent variables. The analysis falls short of the author's original goal of constructing a predictive model for Interstate highway interchanges but provides insight into the interchange development process. Twark recognized that the eventual outcome of his analysis was limited by his use of a small number of study variables because other factors that he omitted must influence if not determine development. More important, the timing of his analysis prevented its success. The author states that the "relative newness" of the Interstate system is the "single most important factor in preventing the development of an appropriate model at this time (1967). . . ." Interstate highway construction began in 1956.

Much of the inquiry directed toward Interstate highway interchanges to date suffers an inexplicable urban or suburban bias *(4, 18, 19)*. This prejudice against nonmetropolitan areas exists in part because of the system's orientation toward cities (most cities with more than 50,000 inhabitants are linked) and because urban highways directly influence more people and are more highly visible to the general population including researchers. In the literature, Interstate highway interchanges are recognized as focal points at which access to the system is possible and the impact of the network on the community is greatest. Urban interchanges have been characterized by their ability to alter traffic flow and patterns, stimulate commercial activity, displace and recreate housing opportunities, and influence industrial location decisions. Conversely, nonmetropolitan interchanges have been viewed as isolated rural crossroads, oases for passers-by, and access points to nearby small towns or tourist attractions. In opposition to traditional theory, this investigation elevates the importance of nonmetropolitan Interstate highway interchanges and their role in fostering local and regional change. In addition, three case studies are provided that strengthen the notion that certain interchanges perform definite functions as central places. The ideas central to this inquiry are that (a) some nonmetropolitan interchange-related development is multifunctional in that it serves the local community as well as the Interstate population and (b) a portion of these dual-purpose intersection communities are actually examples of a new type of urban place, an interchange village. The existence of urban and suburban interchange "clusters" and "nucleations" is well documented, and it follows that nonmetropolitan centers of activity will eventually surface to meet the demands of rural residents and those attempting to gain access to more remote rural areas. A few investigations center on nonurban interchanges *(17, 20, 21)*, but most are dated because they were performed during construction when, instead of a network, the Interstate highway system was a scattered array of unconnected transport links. Nonmetropolitan interchanges carry many of the attributes of their urban counterparts (improved access and high visibility), yet they have gone virtually unnoticed in recent interchange analyses.

METHODOLOGY

The primary goal of this project is to evaluate a number of nonmetropolitan Interstate highway interchanges and to identify evidence of local central place formation. In an effort to accomplish the task it was necessary and informative to (a) identify the presence of the Interstate highway system in an area, (b) define and measure the amount of local development at interchanges along certain nonmetropolitan links of the system, and (c) search for evidence that some highly developed interchanges actually function as central places.

Kentucky is ideal for such an investigation because it is transected by five widely representative Interstate highways of different type, age, and direction (Figure 1). The state is known for its regionality and provides researchers with examples of how interchanges evolve under different spatial circumstances. Local Interstate highway construction began in Jefferson County during 1956, the year of the system's birth. Since then, large parts of the state have been incorporated into the network. I-24 passes through Paducah connecting Nashville, Tennessee, with I-57 to the west. Louisville, Elizabethtown, and Bowling Green lie along I-65 between Indianapolis, Indiana, and Nashville. Louisville, Kentucky's largest urban area, also serves as a terminal point for I-71 from Columbus and Cincinnati, Ohio. I-64 passes through Ashland, Lexington, Frankfort, and Louisville as it connects Charleston, West Virginia, and St. Louis, Missouri. Central Kentucky is further connected to southern Ohio by I-75 that passes through Lexington and Richmond in route to Knoxville, Tennessee.

Total Interstate surface has grown to 1,187 km since construction began in the state in 1956, and current annual vehicle kilometers exceed 9 billion. The Interstate system makes up only 1.1 percent of Kentucky's total highway mileage but carries 23 percent of the traffic (a figure almost identical to that of the entire system). Each highway crosses a nonmetropolitan area in route to larger urban places—St. Louis, Cincinnati, Nashville, or Knoxville. Forty counties and each of Kentucky's major cities are incorporated into the national Interstate network. Each link of the system through Kentucky contains nonmetropolitan interchanges: points at which the system's impact is greatest and most visible and that permit local access, facilitate interregional travel, and provide increased access to a variety of goods and services not only for interstate travelers but for local residents as well. Sixty-five nonmetropolitan interchanges scattered across Kentucky exhibit varying degrees of associated development and consequent influence on surrounding regions.

Twark *(17)* identified the "interchange community" as an area within 0.8 km of the Interstate highway's intersection with another road, and these 203-ha zones of maximum influence are used as individual study areas in this investigation. Structures within each of these circular study areas, which are 1.6 km in diameter, are classified according to size and function. Types and sizes of existent buildings were evaluated during prestudy field testing and grouped for simplification. The structural categories identified are (a) simple, nonresidential; (b) single-family residential; (c) multifamily residential; (d) small commercial and small institutional; (e) large commercial, large institutional, and small industrial; and (f) large industrial. Preliminary examination of recent aerial photographs and topographic maps of each interchange area facilitate further field investigation. Field tests, aerial photographs, maps, and finally fieldwork (counting and classifying structures) all work in

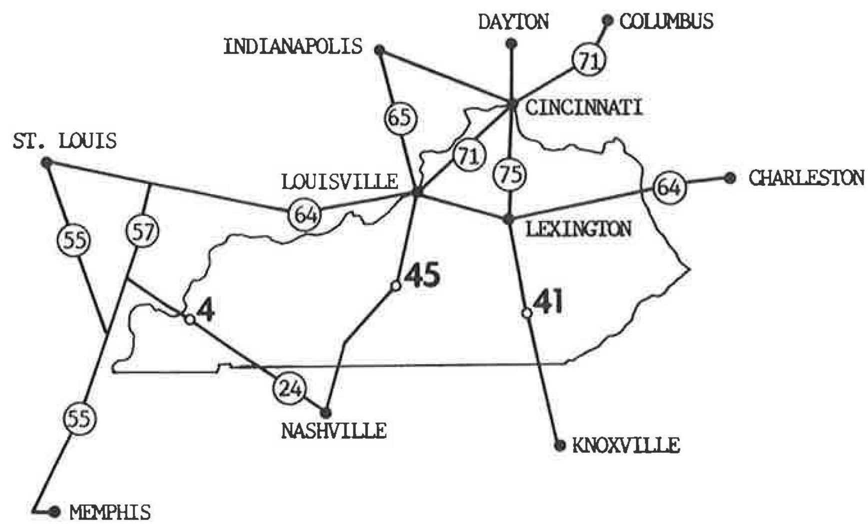

FIGURE 1 Interstate highway system through Kentucky.

conjunction to create an effective and generalizable methodology for this and future interchange projects.

RESULTS

During the summer of 1985, every building within each of the 65 study areas was counted and classified according to its use. Overall, 13,195 ha of property were field surveyed and 6,670 structures were recorded and classified. Observed types of buildings ranged from simple farm barns to multilevel regional shopping malls. Various structure types were classified according to size and ability to generate activity (Table 1).

TABLE 1 BREAKDOWN OF TYPES AND NUMBERS OF STRUCTURES AT 65 NONMETROPOLITAN INTERCHANGES

Category	Total No.	Avg No.	Percent
Simple, nonresidential	2122	32.65	10.08
Single-family residential	3083	47.43	29.29
Multifamily residential	184	2.83	3.50
Small commercial and small institutional	1077	16.57	40.94
Large commercial, large institutional, and small industrial	195	3.00	14.82
Large industrial	9	0.14	1.37
Total	6670	102.62	100.00

Aside from the surprisingly large number of structures centered around these relatively remote interchanges, the mixture of building types and functions is particularly interesting. As might be expected, a significant proportion of firms located at interchanges are transport related (service stations, restaurants, and motels) but an equally meaningful number of structures is dedicated to local, regional, or multiple functions. Functions of structures were often found to be inconsistent with those associated with through travel. For example, nonmetropolitan interchange locations were chosen by local, state, and federal government agencies for local and regional offices. Agencies such as the U.S. Bureau of Surface Mining and the Kentucky State Police are distinctly regional in nature and serve large parts of the state from their offices placed near nonmetropolitan interchanges. Schools and churches are oriented toward smaller, local populations and also operate within several study areas.

The area around each study interchange is different; each is characterized by varying numbers and types of structures serving quite distinct purposes. However, two obviously divergent groups of nonmetropolitan interchange communities currently operate within Kentucky. A small percentage of the state's interchange areas is characterized by excessive numbers and blends of structure types and functions, and a second group of less-developed areas, which exert less influence, meets rather limited demands for fewer goods and services. When an interchange community has a diverse mixture of transport-related and community-specific establishments, its role is that of a central place, and, if that mixture is broad based and large enough in scope, the community, for all practical purposes, serves as an urban place—an "interchange village." These villages are centers of commerce and administration that furnish residents and passers-by with goods and services. They often serve as a hub, the focus of a community's religious, educational, and entertainment activities.

Six of the 65 interchanges studied qualify as interchange villages because of significantly greater concentrations of diverse development (this distinction is noticeable not only on paper but on the landscape as well). Within this smaller group of interchange villages, different functions appear to be served. Most obvious are the distinct roles of certain interchange villages as nucleations of larger urban places, centers focused on tourism, or regional hubs. The following three villages serve as examples of each functional type.

Interchange 4 (as numbered by the Federal Highway Administration) on I-24 is an example of a multifunctional interchange village. When opened to traffic in 1974, the interchange lay in rural McCracken County approximately 5 km from the city of Paducah with its population of 29,000. Aerial photographs indicate that before construction of the interchange only 53 structures existed within the study area. Fifty-two of these structures were either single-family residences or uninhabited farm barns, sheds, or garages. Currently, 247 structures lie within this once-rural, predominantly agricultural area. The single most significant feature of this interchange village is the Kentucky Oaks Mall—the largest in the state.

Within the village, 173 structures are commercial establishments and 74 are residential or housing related. Several service stations and truck stops are located near the intersection to capture the attention of through traffic but are considerably larger than those firms located at other interchanges that rely exclusively on the superhighway for their clientele. The retail businesses of this village appear to profit by tapping two distinct populations: that of I-24 and that of the surrounding region that may or may not use the Interstate highway to gain access to newfound shopping opportunities.

Although this particular village serves western Kentucky and southern Illinois via I-24, it is accessible to the residents of Paducah on what was once a narrow rural road but has since been upgraded to meet the needs of nearby urbanites.

A regional social characteristic that enhances the village as a central place is its legal classification as a "wet" area in which the sale of alcoholic beverages is allowed. Baerwald *(18)* noted the influence of such zoning on suburban interchange development, but the impact of regional classification variability on nonmetropolitan communities was previously unknown. Because this interchange is the nearest location of wet restaurants and retail stores for hundreds of thousands of people, its role as a central place is amplified.

A second but quite different type of interchange village has developed near Interchange 45 in Barren County. This interchange is one of only three along the Interstate system that allow entry into Mammoth Cave National Park. Before the opening of the interchange in 1969, this was a dairy-farming area that had seven houses and twelve barns. Today, the interchange village is made up of 5 large commercial; 45 small commercial; 9 single-family; and 31 simple, uninhabited structures. Billboards located more than 35 km to the north and south of this interchange on I-65 advertise more than 1,000 motel rooms and more than 25 restaurants at this "regional convention center." In addition to the variety of restaurants frequented by locals, the largest grocery stores in the county are conveniently situated within this new "town." Even though Interchange 45 lies within a "dry" county, its restaurants, motels, and retail outlets flourish because of a steady stream of tourists through the village.

The developed area immediately surrounding Interchange 41 in Laurel County represents a truly regional interchange village. The interchange is formed by the intersection of I-75 and Route 80 of the Appalachian Development Highway System and was opened to traffic in 1969 in an area previously held by small tobacco farmers. The purpose of the regional Appalachian highway project was to reduce the isolation of areas such as eastern Kentucky *(22)*. Route 80 and the other links of the Appalachian Development Highway System transect the area connecting small towns with each other, larger urban places, and the Interstate highway network.

Interchange 41 is the one point in Kentucky where the regional and national Interstate networks intersect. If the two highway projects have achieved their respective goals of regional and national connectivity, then this particular point is unique in that it allows intra- as well as interregional access. Close examination of the entities located within the village around Interchange 41 indicates that members of both public and private sectors are aware of the advantages associated with locating there.

For example, an office complex near the interchange houses regional branches of both state and federal government agencies. In addition, a school and two churches are found within the immediate interchange area. This interchange village illustrates the wide variety of users that can be found along nonmetropolitan links of the premier transportation network of the United States (Table 2).

TABLE 2 NUMBER OF STRUCTURES BY TYPE AT INTERCHANGE 41

Type	No.
Simple, nonresidential structures	17
Single-family structures	22
Small retail firms	23
Government offices	11
Wholesale outlet stores	5
Wholesale supply firms	4
Motels with restaurants	2
Churches	2
Lumber yard	1
Large equipment sales and repair	1
Mobile home distributor	1
Milk processing factory	1
Elementary school	1
Total	91

Although designated "dry" and far from a measurable urban population or a significant tourist attraction, this interchange satisfies a different locator demand. Compared with other interchange villages that are supported by nearby urban or tourist populations, this central place is unique in that regional access is its predominant feature. Of the six interchange villages identifiable in Kentucky, two function as regional centers, three are supported by local urban populations, and one is tourist driven.

Given the level and diverse nature of nonmetropolitan interchange villages, why have researchers failed to recognize the implications of these recently developed urban places? One explanation of this failure lies in the village and the way it was formed. Corsi *(23)* characterized nonmetropolitan interchange areas as relatively undeveloped except for a few service stations that located immediately after the interchange was constructed. Most nonurban interchanges exhibit this development pattern, but some eventually accrue other entities depending on the site and situational characteristics of the area and the interchange. Temporal examination of interchange villages reveals a patterned development process that explains the omission of such villages from modern urban thought (Figure 2).

Corsi's evaluation of spontaneous small-scale transport-related facility location is accurate, but two additional "waves" of activity appear to follow. These distinct periods of development can be characterized by the scale of investment required to set up a particular type of firm *(24)*. After initial interchange activity, there occurs a lull in development that is followed by construction of mid-level structures. For example, motels, larger truck stops, churches, and schools often appear during

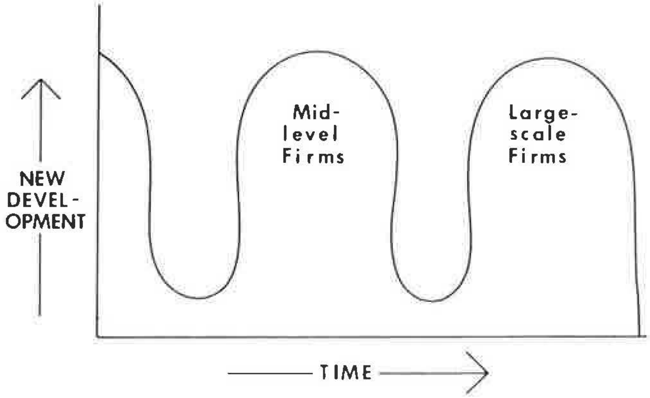

FIGURE 2 Interchange village development over time.

this intermediate period. If a third wave occurs, it is usually typified by large-scale commercial, industrial, or institutional development such as shopping malls, factories, or hospitals. Reasons for the lag in time between these periods of activity may lie in the additional time necessary to implement a larger project or to acquire more substantial quantities of capital. Developers may assume a "wait and see" attitude toward construction that involves potential traffic volume or other investor decisions. Often, the initial developmental surge that Corsi recognized is the only activity that will occur near a particular interchange. However, the second and still more infrequent third waves do occur and consequently deserve scholarly attention.

SUMMARY AND CONCLUSION

All nonmetropolitan Interstate highway interchanges are not remote crossroads, oases of traveler services, or mere access points to other places. Likewise, not all that serve as central places evolved because of local urban demands, tourist attractions, or particular regional characteristics. However, there should be little doubt that nonmetropolitan Interstate highway interchanges are more important locational factors than they once were. Multinational corporations (Toyota and General Motors) have recently announced plans to locate industrial complexes at interchanges in Kentucky and Tennessee, respectively. Officials from both firms identified the superhighways and interchanges as prime factors in their location decisions *(25)*.

In spite of the type and quantity of existent development within interchange villages and the increasing global importance of interchange location, these areas remain largely unregulated and unaddressed by scholars and by local, state, regional, and national government officials.

Problems have arisen and will continue to arise at these points of magnified system impact. They will necessarily demand attention as they develop demands for traffic control and other services. Does interchange village morphology resemble that of many small towns where commercial and other development occurred at more important crossroads? How will already understaffed rural law enforcement agencies meet the legal needs of interchange villages? Because each of these villages exists in an area without any form of zoning or land use regulation, will conflict arise between land users with contradictory goals? How will the future infrastructure requirements of interchange villages be met? While these and other questions remain unanswered, a new subject area for those interested in urban and central place development exists. Although the presence and circumstances of urban and suburban interchanges are quite well documented, nonmetropolitan interchange development was previously absent from the literature.

Researchers need to develop an ability to forecast interchange village evolution and to identify the triggers of this urban growth. The stage is set for future comparisons between nonmetropolitan villages and their urban counterparts. Scholars must first realize the existence of interchange villages and then focus on their patterns of occurrence as well as their generalizable morphology, if possible. This investigation identifies a new type of urban place and calls attention to the criticality of recognizing interchange villages as centers of increasing nonmetropolitan land use activity.

REFERENCES

1. C. Goodrich, J. Rubin, H. J. Cranmer, and H. H. Segal. *Canals and American Economic Development.* Kennikat Press, Port Washington, N.Y., 1972.
2. J. R. Stilgoe. *Metropolitan Corridor: Railroads and the American Scene.* Yale University Press, New Haven, Conn., 1983.
3. G. W. Hilton and J. F. Due. *The Electric Interurban Railways in America.* Stanford University Press, Stanford, Calif., 1964.
4. R. A. Erickson and M. Gentry. Suburban Nucleations. *Geographical Review*, Vol. 75, No. 1, Jan. 1985, pp. 19–31.
5. W. L. Garrison. Supply and Demand for Land at Highway Interchanges. *Bulletin 288*, HRB, National Research Council, Washington, D.C., 1961, pp. 61–66.
6. S. P. Walsh. Some Effects of Limited Access Highways on Adjacent Land Use. *Bulletin 227*, HRB, National Research Council, Washington, D.C., 1959, pp. 78–82.
7. M. C. Flaherty. Commercial Highway Service Districts and the Interstate. In *Highway Research Record 96*, HRB, National Research Council, Washington, D.C., 1965, pp. 8–18.
8. F. I. Thiel. Highway Interchange Area Development. In *Highway Research Record 96*, HRB, National Research Council, Washington, D.C., 1965, pp. 24–45.
9. E. V. Kiley. Highways as a Factor in Industrial Location. In *Highway Research Record 75*, HRB, National Research Council, Washington, D.C., 1965, pp. 48–52.
10. R. S. Graybeal and J. V. Gifford, Jr. Impact Model of Transportation Systems on Land Values. *The Annals of Regional Science*, Vol. 2, No. 2, Dec. 1968, pp. 153–160.
11. J. B. Mason and C. T. Moore. Commercial Site Selection at Interstate Interchanges. *Traffic Quarterly*, Vol. 27, No. 1, Jan. 1973, pp. 19–33.
12. C. F. Kovacik. Restaurant Patterns in South Carolina. Presented at the Southeastern Division of the Association of American Geographers, Nov. 1985.
13. W. F. Babcock and S. Khasnabis. A Study of Land Development and Traffic Generation on Controlled-Access Highways in North Carolina. In *Highway Research Record 467*, HRB, National Research Council, Washington, D.C., 1973, pp. 34–37.
14. R. C. Deen. *Impact of I-75 on the Local Economy Between Walton and Georgetown.* Research Report. Department of Highways, Commonwealth of Kentucky, Frankfort, Feb. 1966.
15. P. D. Cribbins, W. T. Hill, and H. O. Seagraves. Economic Impact of Selected Sections of Interstate Routes on Land Value and Use. In *Highway Research Record 75*, HRB, National Research Council, Washington, D.C., 1965, pp. 1–30.
16. R. H. Ashley and W. F. Berard. Interchange Development Along 180 Miles of I-94. In *Highway Research Record 96*, HRB, National Research Council, Washington, D.C., 1965, pp. 46–58.

17. R. D. Twark. *A Predictive Model of Economic Developments at Non-Urban Interchange Sites on Pennsylvania Interstate Highways.* The Pennsylvania State University, University Park, June 1967.
18. T. J. Baerwald. Land Use Change in Suburban Clusters and Corridors. In *Transportation Research Record 861*, TRB, National Research Council, Washington, D.C., 1982, pp. 7–12.
19. F. I. Thiel, R. D. Mingo, and J. A. Fields. Use of Space in Highway Impact Zones. *Transportation Engineering Journal*, ASCE, Vol. 102, No. TE4, Nov. 1976, pp. 727–736.
20. T. H. Eighmy and J. J. Coyle, Jr. *Toward a Simulation of Land Use for Highway Interchange Communities.* The Pennsylvania State University, University Park, 1967.
21. W. L. Garrison, E. M. Horwood, and D. F. Marble. *A Study of Land Development Problems at Freeway Interchanges.* University of Washington, Seattle, March 1960.
22. *Appalachia Today: Issues and Problems.* Appalachian Regional Commission, Washington, D.C., 1977.
23. T. M. Corsi. Development at Interchanges: The Ohio Turnpike. *Traffic Quarterly*, Vol. 29, No. 1, Jan. 1957, pp. 65–79.
24. H. E. Moon, Jr. *The Loss of Farmland: The Process of Urbanization in Alabama's Black Belt.* The University of Alabama, Tuscaloosa, 1984.
25. D. Smith. Interstate System: Over Budget, Wearing Out. *Lexington Herald-Leader*, Kentucky, Sept. 15, 1985.

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Issues in Planning for the Transportation Needs of Advanced-Technology Firms

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The Commonwealth of Pennsylvania is actively encouraging the development of advanced-technology industries. Recognizing the importance of transportation infrastructure, the Pennsylvania Department of Transportation has sponsored research at the University of Pittsburgh to understand the relationship between transportation facilities and services and the needs of advanced-technology firms and to determine if current transportation policies and programs adequately address these needs. A brief summary of that research is presented here. Described are the research plan, the results obtained through a telephone survey of advanced-technology and non-advanced-technology firms, and some of the recommendations concerning management of local transportation systems. The primary focus of the paper is the implications of this research—methodological issues that can benefit researchers and substantive issues that can help transportation practitioners. Analysis of the methodology used indicates the need for comparing samples of advanced-technology and non-advanced-technology firms and suggests refinements to the definition of advanced technology. Questions are raised about the transportation needs of advanced-technology firms and government responsibilities for addressing transportation problems.

The Commonwealth of Pennsylvania, in response to the decline of its mature manufacturing industries, is actively encouraging the development of new growth industries. As is the case in many other states, this attention has been focused on "advanced-technology" industries.

Recognizing the importance of transportation infrastructure to the establishment, expansion, and retention of advanced-technology industries, the Pennsylvania Department of Transportation (PennDOT) has sponsored research at the University of Pittsburgh directed at understanding the impact of transportation access and other locational factors on advanced technology firms and evaluating current policies and programs in relation to the transportation needs of these firms. The purpose of this paper is to discuss some of the implications of this research—both methodological issues that can benefit researchers and substantive issues that can help transportation practitioners.

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SUMMARY OF RESEARCH

Research Plan

The objectives of the research sponsored by PennDOT at the University of Pittsburgh were to (a) understand the relationship between transportation facilities and services and the needs of advanced-technology firms, (b) determine if Pennsylvania's current transportation policies and programs adequately address these needs, and (c) make recommendations.

This research project had two phases. The first phase was identification of advanced-technology firms in Pennsylvania. From a short screening survey, firms within five transportation corridors were selected. The corridors were (a) Parkway East, Pittsburgh; (b) Route 202, Philadelphia; (c) Allegheny Valley Expressway, Pittsburgh; (d) State College; and (e) Allentown-Bethlehem-Easton. The purpose of this survey was to gain information about the relative importance of transportation to current business activities of the firms as well as some basic knowledge about the firms. Each firm was described by sector type (i.e., producing a product or providing a service), size defined by the total number of employees, age of technology used in production, and a Standard Industrial Classification (SIC) definition of advanced technology.

The results from this survey were described elsewhere *(1)*. The major finding was that an SIC-based variable contributed little to the prediction of transportation service preferences of the screening survey respondents, whereas such variables as sector type, firm size, and age of technology used in production were important in selecting samples for analysis.

The second phase was an extensive telephone survey of paired samples of advanced technology firms and non-advanced-technology firms in each of the transportation corridors. Comparisons were then made between these two groups of firms to discover if significant statistical differences existed between advanced-technology and non-advanced-technology firms.

The telephone survey identified the unique problems and needs of the advanced-technology firms. Then transportation planning documents from the Pennsylvania Department of Transportation and the local metropolitan planning organizations were analyzed to determine how well these agencies were meeting those needs. Recommendations were offered to help government solve the transportation problems of advanced-technology firms.

Survey Results

The final report to PennDOT, *Transportation Access and the Location of Advanced Technology Firms in Pennsylvania*, was released in June 1986 *(2)*. The following list is a summary of some of the survey results that are important to planning for the transportation needs of advanced-technology firms. (All reported differences between advanced-technology and non-advanced-technology firms are statistically significant at the 0.01 or 0.05 level, using standard procedures of one-way analysis of variance and homogeneity tests.

- Property reasons, which include availability of a suitable site, location within an industrial park, reasonable cost, prestigious address, and pleasant surroundings, are more important to the location decisions of advanced-technology (AT) than non-advanced-technology (non-AT) firms.
- Transportation facilities and accessibility (such as general accessibility, access to particular areas within the regions, and access to facilities including highways in general, particular Interstates, state highways, and airports) are more important to AT firms than to non-AT firms in their location decisions.
- Highway transport modes are dominant for both AT and non-AT firms, but the mix of modes is different. Express parcel delivery is more important for AT firms and truck is more important for non-AT firms.
- Air transport is more important for AT than for non-AT firms.
- Business travel by air is used to a greater extent by AT firms than by non-AT firms.
- Markets for AT firms are more national and international than for non-AT firms.
- University and college facilities are used more often by AT than by non-AT firms.
- Highway problems are most often cited by both AT and non-AT firms as transportation system concerns.
- Traffic problems are cited more often by AT firms than by non-AT firms.

Recommendations

Two of the recommendations to PennDOT concerned management of the local transportation systems. First, PennDOT should develop more direct mechanisms for improving local traffic management and enforcement. This may require the commitment of new resources to local governments to encourage them to meet basic standards in traffic surveillance, enforcement, and operations. A substantial improvement in the level of traffic signal monitoring and maintenance would go a long way toward meeting many of the local traffic concerns expressed by advanced-technology firms.

Where traffic problems have surpassed the capability of being controlled by relatively low-cost measures, new infrastructure may have to be built. One recommendation being promoted by the commonwealth is public-private partnership to finance specific projects through the cooperation of private developers and the federal, state, and local governments.

WHAT HAS BEEN LEARNED

These results suggest that advanced-technology firms have a different mix of transportation needs and that transportation planning should pay attention to this aspect of economic development. Although the findings presented in the report to PennDOT and summarized in this paper can contribute to "understanding the impact of transportation access and other locational factors to the establishment and growth of advanced-technology firms in Pennsylvania," a more general result of this project can be to help other analysts, as well as transportation practitioners, build on the experience that was gained while conducting this research.

Issues of Research Methodology

Background

At the beginning of the research project, only a few things were believed to be certain. First, a group of industries called high technology, or advanced technology, was emerging as the economic development thrust of the 1980s; and its members might be different from those of the more mature, traditional industries. What actually comprised the advanced-technology group was unclear, although the Commonwealth of Pennsylvania did have a list of SIC codes that was supposed to define the universe of firms.

Second, it was recognized that, to determine if advanced-technology industries were different, advanced-technology firms would have to be compared with non-advanced-technology firms. Surprisingly, few other researchers have made any comparisons between the two groups of firms; their investigations have been limited to such issues as the expansion plans and locational determinants of high-technology industries. They have then compared labor creation rates with the economy as a whole, and locational determinants have often been reported with no frame of reference.

Transportation factors as determinants of location preferences were thought to be of only moderate importance. This introduced the question in the literature of whether high-tech manufacturing firms were "footloose" because they appeared to be less dependent than more traditional manufacturers on access to markets and raw materials for remaining competitive *(3)*.

It was left to the Delaware Valley Regional Planning Commission (DVRPC) to adopt the method of comparing two groups of firms to see if, indeed, there were differences between advanced-technology and other firms in their location criteria and transportation needs *(4)*. The next step would be a research design comparing all characteristics except AT status of advanced-technology firms with those of their non-advanced-technology counterparts.

These considerations led to the two most important initial issues in this research design. They were the definition of what comprises the advanced-technology group of industries and the process to be used for selecting samples of firms for comparison.

What Is Advanced Technology?

The first phase of the research project necessarily required a working definition of advanced technology. After the literature was sampled and no agreement was found on how to define the industries except that, operationally, SIC codes were used, the decision was made to adopt a master list of all of the SIC codes used by other researchers.

For manufacturing firms, this included most of the industries in the following two-digit SIC codes: 28, chemicals; 35, nonelectrical machinery; 36, electric and electronic equipment; 37, transportation equipment; and 38, instruments. A few three-digit SIC codes were included (petroleum refining, reclaimed rubber, and ordnance) as was a four-digit SIC code, games and toys.

Service firms included the industries in the SIC codes: 48, communications; 737, computer and data-processing services; 7391, research and development laboratories; 807, medical and dental labs; and 8922, noncommercial research organizations.

Using these SIC codes to define the industries clarifies several facets of a definition of AT. The products or services are considered advanced technology, and the technical nature of the output implies a proportion of technical workers or research and development expenditures, or both, that is above the average. However, because SIC codes are product oriented, they exclude industries whose products are not considered advanced-technology but that use advanced technology processes.

The listing of AT firms in Pennsylvania relied heavily on SIC codes because this identification was readily available. An attempt was made to include firms that used AT processes but did not produce AT products by searching U.S. Securities and Exchange Commission disclosure statements, but these are available only for publicly traded companies and would not include private, probably small, firms that may be experimenting with new processes to produce traditional products. Some of these firms were captured by the third method used to produce the directory, which was self-identification. Searching membership lists of organizations involved with economic development revealed the names of member firms not listed elsewhere that could be added to the AT directory.

The result of this three-step process was the development of a machine readable directory of approximately 4,000 advanced-technology firms in Pennsylvania *(5)*. About three-quarters of the entries in the directory came from published sources that were searched using SIC codes. The other one-quarter was added by using the other two methods.

There was a trade-off inherent in the process used to develop the directory of AT firms. AT firms that might be missed using only SIC codes were included, at the cost of adding firms that would not be defined as AT on closer examination.

The type of firm-based survey research proposed for this project revealed another problem: Many plants are part of a larger company with diverse operations in many locations. A company might be classified by SIC code as AT, but the plant itself should not be included.

The solution must be to decide on a case-by-case basis about including or excluding a firm. For this research project, decisions on some firms could only be made after considering the type of product or service and the age of technology used in production after this information was gotten by means of a telephone interview. In this type of firm-based survey research, a random sample selected by the computer is not desirable. Because the intention in producing the directory was to be sure to include all AT firms, the error of including firms that might not be AT was allowed. Therefore a judgmental approach is necessary to select the true AT sample. If this approach had not been used, approximately 16 percent of the firms would have been incorrectly classified as AT, a considerable margin of error when using statistical procedures to evaluate differences.

Using Samples for Comparisons

The next issue concerned the way in which the analysis would be conducted. It would not be sufficient to base policy on frequencies of responses by advanced-technology firms with no reference to how non-advanced-technology firms would respond. Instead, comparisons must be made between advanced-technology and non-advanced-technology firms. Relatively simple statistical tests can be used for this type of analysis, providing that the samples are comparable in everything except that which is being analyzed.

The two samples of firms should be similar in sector type, location, and size. In each of the five corridors, equal numbers of AT and non-AT firms were selected. In addition, the AT–non-AT pair in each corridor contained relatively similar proportions of service and manufacturing firms. The two groups of firms were also similar in their overall size distribution.

Although the AT definition in its broadest sense was the criterion for selecting samples, many of the characteristics attributed to AT firms are not readily available to confirm the choices. The telephone survey was designed to provide information that the samples did indeed differ in advanced technology status. Compared with non-advanced-technology firms, the characteristics of the advanced-technology firms follow those that can be described in the literature: employing more salaried employees, using fewer hourly employees, having been established more recently, using newer technology, planning to expand, and even having more employees working on flextime. Therefore it is important to be able to say that samples differ only in the characteristic of interest, AT status, and that results can be truly attributed to differences between the two groups of firms.

In the original experimental design, the proposed analysis was to be by paired difference tests. In the analysis actually performed to determine differences between AT and non-AT firms, pooled difference hypothesis tests were used instead because the strength of the sampling process allowed these simpler testing methods. Statistical procedures available in packaged programs such as SPSS *(6)* and SAS *(7)* easily produced the results necessary to fulfill the objectives of the research project. This reinforces the benefit of spending time and attention carefully selecting samples that differed only in AT status.

Further Questions

A few methodological issues remain for future consideration. Preliminary analysis of the screening survey indicated that the age of technology used in production was an important variable. Unfortunately, this information is not ordinarily used to describe a firm and can only be obtained by contacting the firm. Also, this procedure works much better for manufacturing firms than for service firms. If the process used to produce a product or provide a service is recommended as a factor in defining advanced technology, then work still has to be done to make the choices clear to the respondent.

In this research, the respondent was asked to classify the age of technology used in producing the firm's primary product or service. Choices were less than 1 year, 1 to 5 years, 6 to 10 years, 11 to 20 years, and more than 20 years.

It should be recognized that this was one way to help the respondent understand the question and be able to answer without much hesitation. Other methods may be more easily understood and give more precise information. For example, product and industry life cycles are two perspectives that should be considered *(8)*. The life cycle of a product consists of four phases: (a) the new product is launched commercially and sales rise slowly, (b) sales increase, (c) sales stabilize, and (d) sales decline with the commercial exit of the product. The industry technology cycle consists of three stages: (a) invention, (b) innovation, and (c) standardization. These categories may be adapted to better fit the processes used by the AT firms to produce products or provide services.

A second issue involves the growth potential of these firms. Are the firms of interest advanced technology or are they the firms that will contribute jobs to a local economy? Every AT firm is not a growth firm and every growth firm is not an AT firm.

A third issue is combining service and manufacturing firms in the AT grouping. Service firms have been added to the discussion in only some cases. To many, AT means manufacturing firms. Those researchers who do include service firms generally limit them to communications and computer programming, probably relying on the production of an AT service as the criterion. Ambiguity arises about including firms that use AT processes to provide a non-AT service (e.g., use of state-of-the-art bar coding procedures in grocery stores) and firms that support AT manufacturing as wholesalers of electronic components.

These are a few of the methodological questions raised by the kind of research described here. Discussions will help not only investigators concerned with advanced-technology firms but those engaged in firm-based survey research for economic development as well.

Issues Raised by Results

One objective of this research was to determine the transportation needs of advanced-technology firms. Because so much attention had been given to the problems of defining advanced technology, selecting samples that could be compared, and determining the methodology for statistically testing differences, it was a relatively simple matter to obtain results about the unique way in which advanced-technology firms use transportation facilities and services.

Issues Involving Location Choices

Researchers on this project were careful to specify the unit of analysis for the location question as "within a ten minute driving radius." Results can be compared with those of other studies of locational preferences only after considering how the question was asked. Other studies have used regions within the United States, comparing the seven areas of New England, Midwest, Mideast, South, Southeast, Mountain and Plain States, and Far West or choosing a region within a state.

By asking the respondents why they chose a particular site instead of a nearby site, this research was really asking about what makes a property attractive to a firm. Because this unit of analysis was used, the research was highly influenced by the view that the advanced-technology firms in Pennsylvania did not consider locations in many parts of the United States, but were home-grown—"conceived, born, nurtured, and grown in place" *(9)*.

Given this view that the AT firms in Pennsylvania considered a limited number of options when selecting a site, it was not unexpected that property reasons would be most frequently mentioned by the firms. In this research project, the firms were located in five corridors throughout the state. The two corridors in Pittsburgh were predominantly suburban. One of these corridors was entirely suburban and contained a publicly funded regional industrial park. The other corridor was a mix of firms in suburban locations, a few firms in the central business district, and firms in the university district within the city. In Philadelphia, the corridor was suburban and included a large, privately developed industrial park. The other two corridors consisted of a university town in rural Pennsylvania and an area of three closely related small cities.

What was not part of this research was consideration of the urban firms' reasons for locating at their particular sites. The phrasing of the question using the 10-min driving radius would have given the urban firm the opportunity to consider suburban locations. In the preliminary screening survey, all AT firms in Pennsylvania were contacted by mail and asked why they selected their particular location instead of another location in the area. Of those that responded to that question, 77 were located in center city, Philadelphia. Although this survey was different from the detailed telephone survey that has been reported, it may be useful to mention the results from the location question.

In the screening survey, only one-quarter of the firms mentioned property as a reason for location whereas nearly one-half of the AT firms in the telephone survey mentioned property reasons. Also, 35 percent of the center city firms mentioned business reasons, but only about 16 percent of the AT firms gave such reasons in the telephone survey. Because the surveys are quite different, these results are not meant to be used in a statistical analysis of center city versus suburban firms. However, it does point up the need for research. It is an important research question because different strategies are perhaps needed for urban AT development than for suburban AT development.

In an urban area, proximity to customers may be most important. Therefore, government policies that advocate property development in the center city (the use of abandoned inner-city factories, warehouses, and offices as advanced-technology incubator space) may not be cost-effective. Perhaps government intervention that might work in the suburbs has to defer to the marketplace in the center city.

On the other hand, a few of these firms did mention that their reason for locating at their sites was the University City Science Center, a downtown research park with close relations with the University of Pennsylvania and Drexel University. When considering urban spaces for AT firms, a link may have to be made to a university. Future research should consider whether the urban space near the university has the proper cost-benefit ratio to justify its development.

Using the area within a 10-min driving radius as the unit of analysis, it was clear that transportation facilities were significantly more important to advanced-technology firms. Also, sensitivity to traffic congestion was found to be significantly more important to AT than to non-AT firms. These conclusions are important because they highlight the need for local governments to pay attention to transportation. Together with the conclusion about the need for appropriate property sites, the conclusions about AT development—at least in Pennsylvania and probably in other states with potential for suburban and small city development—are really directed to implementation by local municipal officials.

Transportation Needs of Firms

Both AT and non-AT firms rely on trucks to deliver their products and private automobiles to get their employees to work. Therefore, in terms of an economic strategy, any projects to improve the road system will benefit a wide constituency.

Both groups also rely on highway-dependent modes to receive their raw materials and supplies. Suppliers ship by truck more often to non-AT firms than to AT firms and by express parcel delivery more often to AT than to non-AT firms; nevertheless, both are highway-dependent modes. Although it was hypothesized that the pattern for suppliers would be the same as that for firms shipping their products and services, this was found not to be true. Nevertheless, it is sufficient to recognize the use of over-the-road transportation modes because any recommendation must include highway improvements.

The most important finding is that a diversified set of transportation modes is used by AT firms to transport their products or services. Use of air service and express parcel delivery is increasing while use of trucks, although important, is decreasing.

Because of the popular notions about advanced technology, air was expected to be an "AT mode" accounting for a high percentage of transport of both products and services. However, only 15 percent of the AT firms did use air, and this type of transport was used for about 8 percent of their products and services, although this use was greater for AT than for non-AT firms. Also, air service was used more often by AT than by non-AT firms for business travel.

It was also expected that at least one of the corridors would be located near an airport. Surprisingly, significant clusters of AT firms were not found around airports; each area did have firms located near its airport, but no well-defined agglomerations were identified. In the AT sample, about 12 percent of the AT firms (19 firms) mentioned proximity to an airport as a factor in making their location decision (for non-AT, the number was 2 firms). Because AT firms are using air for some of their shipments and about half of their business travel, it appears that a regional airport is sufficient for their needs. Government policy, then, should be concerned with a firm's access to a regional airport rather than its proximity.

Certainly, the question of the use of airports is far from settled. It would be interesting to look at firms at varying distances from an airport to determine if those closer to the airport ship more of their products, receive more of their raw materials, and engage in more business travel by air than firms farther from the airport. Perhaps there is a correlation between air usage and distance from an airport.

Besides air, other modes used by AT firms are truck, company-owned vehicles, mail, and express parcel delivery. The difference between AT and non-AT firms in the use of express parcel delivery of products is worth mentioning. The mode includes overnight letters and parcel service, as well as delivery of packages within several days.

This method of transport appears to be particularly important for the strictly defined advanced-technology firms that produce such products as small electronic components and software. Express parcel delivery may actually be multimodal because, although the product leaves the firm by motor vehicle, it may reach its destination by air. Such linkages may show air transport to be much more important than indicated by the percentage breakdowns of mode use.

Corridor-level analysis of the use of different modes suggested some evidence for this. The AT firms in the Allegheny Valley Expressway corridor, a suburban corridor within about a 45-min drive from the Greater Pittsburgh International Airport, used air for about one-quarter of their transport and express parcel delivery for about 30 percent of their transport. On the other hand, the AT firms in the rural State College corridor used virtually no air transport and used express parcel delivery for about 60 percent of their products and services, although their markets were primarily national and international. The question, then, is how actually different are these corridors. What is not known is how much transport is by air. Perhaps both corridors are really quite similar with their products ultimately reaching their destinations by air but by different connections.

It is possible that any problems of getting to the airport and using air service are being transferred to the private sector that operates delivery services. The firms surveyed offered few complaints about air facilities used to transport their products. It cannot be concluded that there are no problems; private services may be bearing the problems. The new actors, then, to whom government officials may have to listen, are the private providers of express parcel delivery services.

The problems that were most apparent were traffic problems, and the AT firms were more vocal about them. Even highway and bridge problems were not as apparent to the respondents as was traffic congestion. Technically, these problems have good potential for being solved. For relatively modest investments, benefits visible to the general public can be obtained.

The problem appears to be the lack of attention given by local governments to the importance of traffic congestion. It is significant that the governor's commitment to advanced-technology economic development may be undermined at the local level by officials who are not aware of the link between traffic congestion and economic development and the need for responding to the problem if development is expected to continue.

The commonwealth, through the use of state and federal funds, has resources to undertake traffic operations projects. However, when a project is completed, responsibility for maintenance of traffic signals and traffic enforcement is given to local officials who must manage the system. The critical problem appears to be that they do not have the resources to do this. The Pennsylvania Department of Transportation can provide technical assistance and funding to local governments to maintain a high level of traffic operations. An objective of this research project was to make recommendations to the department if current programs were found to not meet the needs of AT firms. Alleviating traffic congestion was the most immediate and direct transportation need that was voiced by the firms, and it can be done within the present government structure.

Another prominent recommendation of the research project was the use of public-private partnerships to build infrastructure when low-cost traffic management programs are not sufficient and new capacity must be provided. Because this is a new focus of Pennsylvania government and the first projects are just being built, this analysis did not uncover any problems with the program. Instead, this appears to be the panacea for replacing federal funding that is being decreased.

Future work is needed to test the assumption that public-private partnerships should be pursued to get projects built. After all, this is just another phase in the history of infrastructure financing. First, the government assumed all financing; then, local governments began paying for preliminary engineering studies to advance projects; and, now, governments are entering into partnerships with private developers or local business firms to raise funds to actually construct the projects.

In California, a state that has a longer history of such funding arrangements, the ethics of private infrastructure financing is being questioned *(10)*. Will the public good be served when the communities with the most money and most aggressive developers have their projects advanced?

In Philadelphia, this process is being used by a large local developer to improve his property and enhance his competitive advantage in the Route 202 "High-Tech" corridor. He has recognized that the problem of traffic congestion may cause him to lose tenants to nearby industrial parks served by roads with fewer and less severe congestion problems. In this case, the needs of both the developer and the AT firms coincide. But who is considering the interests of the small developers and poorer municipalities? This also raises those questions about the two styles of property development demonstrated in Pennsylvania: publicly funded industrial parks in the Pittsburgh area and private development in the Philadelphia area. The discussion about public-private partnerships should also include a discussion about who should be doing the developing in the first place.

END NOTE

In the research report to PennDOT many clear results were presented about the transportation needs of advanced-technology firms in Pennsylvania, and this paper summarized these findings. At the same time, the research has probably raised many other analytical questions, and the purpose of this paper has been to offer some direction for future research on both methodological and substantive issues.

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REFERENCES

1. N. P. Hummon, L. Zemotel, A. G. R. Bullen, and J. P. DeAngelis. Importance of Transportation to Advanced Technology Industries. In *Transportation Research Record 1076*, TRB, National Research Council, Washington, D.C., 1986, pp. 1–7.
2. J. P. DeAngelis, A. G. R. Bullen, and N. P. Hummon. *Transportation Access and the Location of Advanced Technology Firms in Pennsylvania.* University Center for Social and Urban Research, University of Pittsburgh, Pa., June 1986.
3. R. Premus. *Location of High Technology Firms and Regional Economic Development.* Subcommittee on Monetary and Fiscal Policy of the Joint Economic Committee, Congress of the United States, 1982.
4. *Transportation Needs for High Technology Firms: Route 202 in Chester and Montgomery Counties.* Delaware Valley Regional Planning Commission, Philadelphia, Pa., Feb. 1984.
5. *Documentation of the Directory of Advanced Technology Firms in Pennsylvania.* University Center for Urban and Social Research, University of Pittsburgh, Pa., Sept. 1985.
6. N. H. Nie, C. H. Hull, J. G. Jenkins, K. Steinbrenner, and D. H. Bent. *SPSS: Statistical Package for the Social Sciences,* 2nd ed. McGraw-Hill, New York, 1975.
7. *SAS User's Guide: Statistics,* Version 5. SAS Institute, Inc., Cary, N.C., 1985.
8. M. D. Thomas. Industry Perspectives on Growth and Change in the Manufacturing Sector. In *Industrial Location and Regional Systems: Spatial Organization in the Economic Sector* (J. Rees, G. Hewings, and H. A. Stafford, eds.), J. F. Bergin, New York, 1981, Chapter 3.
9. D. N. Allen and G. E. Robertson. *Silicon, Sensors and Software: Listening to Advanced Technology Enterprises in Pennsylvania.* The Pennsylvania State University, University Park, July 1983.
10. E. A. Deakin. Ethics of Private Infrastructure Finance. Presented at 65th Annual Meeting of the Transportation Research Board, Washington, D.C., 1986.

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Changing Pattern of Urban Travel and Implications for Land Use and Transport Strategy

F. V. WEBSTER AND P. H. BLY

The Transport and Road Research Laboratory carried out a study of the changing patterns of urban travel for the European Conference of Ministers of Transport. This study examined the various factors that affect the use of public and private transport in cities and concluded that public transport would ultimately decline even in those countries where its use was currently rising. In contrast the factors that favor car use were likely to continue to do so well into the future. In this paper the implications of those findings and some of the options available to policy makers are examined.

Public transport use has been declining for more than 30 years in the United Kingdom, and current land use trends are making it increasingly difficult to provide adequate public transport services in areas where jobs, homes, and other facilities are becoming more and more dispersed. There is concern for those who do not have access to a private car and who are dependent on public transport. There is also concern in many quarters for the urban areas themselves—the increasing urban sprawl, the spread of congestion in both time and space, and the areas of dereliction that are appearing in some of the inner suburbs. Many planners concerned with these problems view with envious eyes some of the more attractive Continental cities, which have managed to remain reasonably compact and to retain thriving centers bustling with life and activity, and where use of public transport is stable, or even increasing. Even so, some policy makers in these countries are worried by the increasing amounts of subsidy absorbed by public transport and by social and economic changes that may adversely affect urban vitality in the future.

The concern for the way cities are developing and the implications of this for travel led the U.K. Transport and Road Research Laboratory to embark on a study of urban travel in a number of different types of cities under the auspices of the European Conference of Ministers of Transport (ECMT), which greatly facilitated the collection of data from more than 100 cities in 16 countries. The work was carried out by the present authors and M. Dasgupta, R. H. Johnston, and N. J. Paulley. The results of the study were presented to the Council of Ministers in 1984 and the report was published by ECMT in 1985 *(1)*.

In this paper a rather qualitative summary is provided of the main findings of the ECMT study, and on this basis the implications for future urban policy are set out. The trends in the main factors that affect the use of public and private travel modes are examined, and how these might change in the future is considered. The options open to policy makers are described, and the likely impacts of adopting particular policies are assessed.

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PAST TRENDS

The main trends affecting travel are those that are concerned with the cost of travel (and the ability to afford it), the quality of travel, the benefits of traveling to particular places, and the relative locations of origins and destinations.

Increasing Affluence

The universal increase in car ownership is a direct result of increasing affluence and there is no sign yet of approaching saturation, even in rich countries like the United States (Figure 1). Having a car available is the biggest single factor affecting use of public transport, and a surprising similarity in the effect of car ownership in different cities and countries was found, as shown in Figure 2. A first car in a household results in a drop in public transport trip making of roughly 40 percent; the addition of a second car removes a further 30 percent of the remaining public transport trips.

Increasing affluence also allows travelers to shift from "cheap" modes, like walking and cycling, to more expensive ones, like car and public transport. Figure 3 shows how car ownership affects trip making by different modes across samples of households surveyed in both Britain and France. The car takes the majority of trips in car-owning households and is likely to be preferred for almost all journeys for which it is both suitable and available, but more affluence will nevertheless generate some extra travel in the form of new trips or extensions to existing ones. Figure 3 shows that car ownership reduces both walking and public transport use overall, but, nevertheless, increasing affluence may encourage some transfer of trips from walking to public transport. This will tend to occur when access times are low (more people will "hop on a bus") and when there is some benefit from taking a longer bus trip to a more distant destination instead of a short walk to a local destination. Journeys by cycle or moped are similar in length to bus journeys so that increasing affluence may well encourage some transfer, though, as Figure 3 shows, trip rates

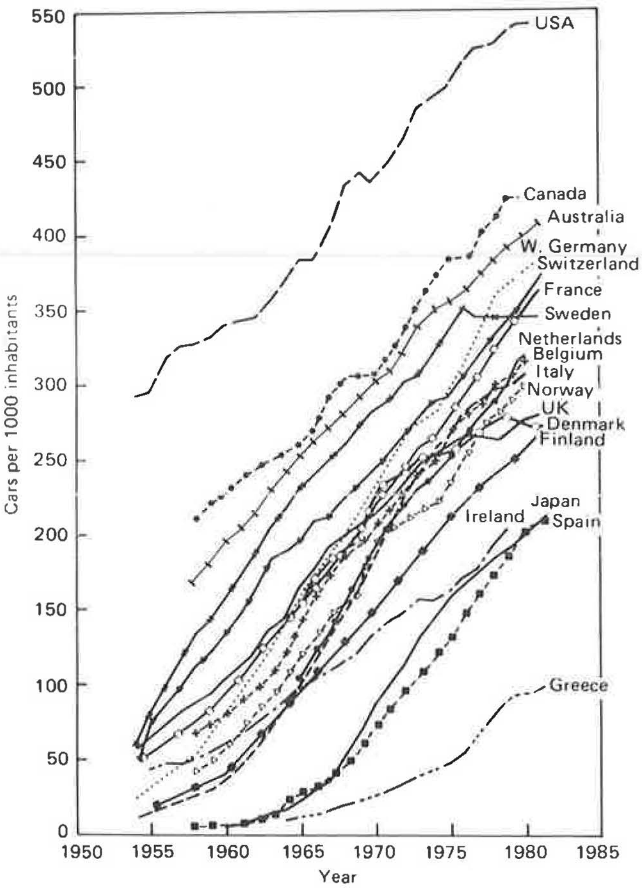

FIGURE 1 Growth in car ownership in a number of countries *(2)*.

by these modes in most British cities are fairly low. In many Continental countries, however, the scope for transfer isgreater, though diminishing. The study showed that transfer from two-wheeled trips to public transport has been an important factor in a number of French cities *(3)*.

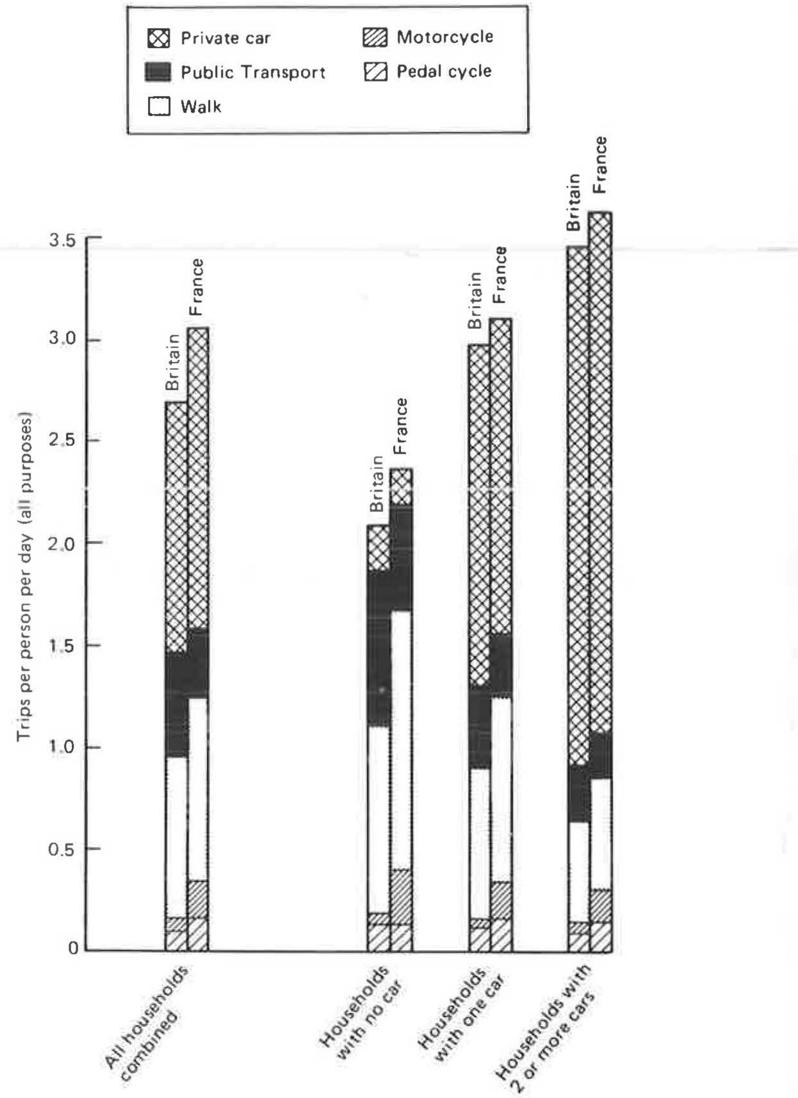

FIGURE 3 Daily trip rates in a sample of major towns in Britain and France for different levels of car ownership.

Price and Quality

Car running costs have remained fairly steady in most countries for many years despite two oil crises in the 1970s. In contrast, almost everywhere despite a general improvement in productivity, but subsidies have cushioned these rises so that in some countries, particularly in Continental Europe, fares have actually fallen. In the United Kingdom, increases in subsidy have not been sufficient to offset rises in costs and the effects of reduced patronage, so fares have risen consistently over the years relative to other prices, causing appreciable reductions in public transport use.

Road network speeds have been relatively constant over the years, though in the larger cities there has been some peak spreading. However, because more and more journeys are made in the outer areas of cities as both population and employment disperse, travel by car is generally becoming faster. In-vehicle speeds of bus travel are probably increasing for the same reason, but total journey speeds (including walking and waiting) are falling in many cities because of the longer access

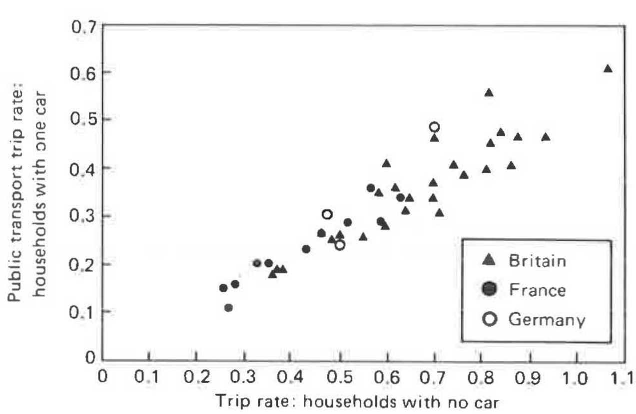

FIGURE 2 Comparison of trip rates for bus and tram of households with and without cars in a sample of British, French, and German cities.

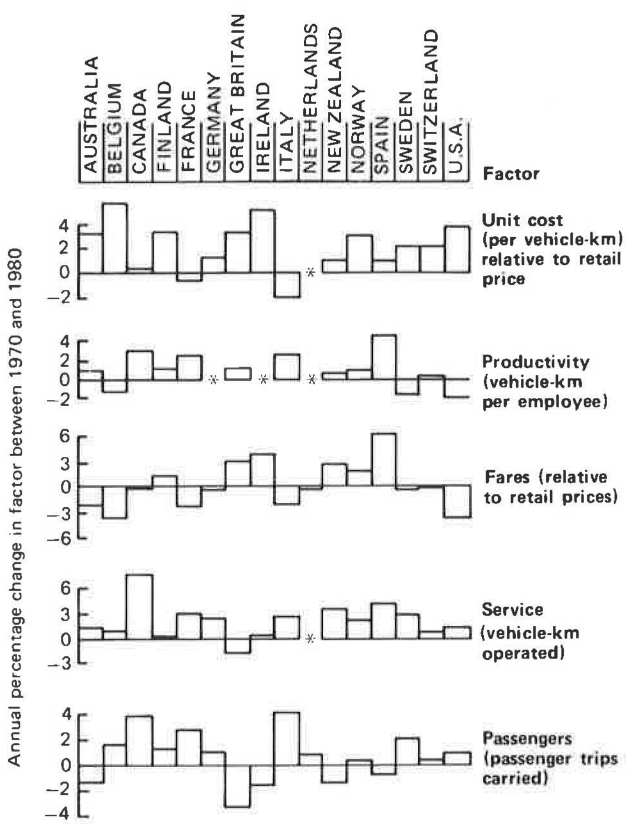

FIGURE 4 Mean annual trends in public transport costs, productivity, fares, service, and ridership between 1970 and 1980.

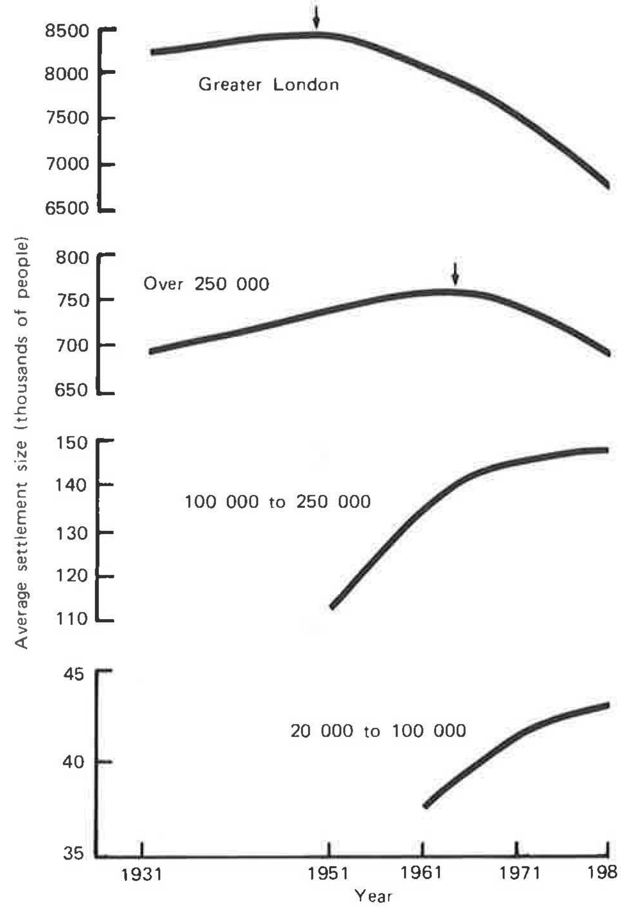

FIGURE 5 Changes in population of towns of different sizes in England and Wales, 1931 to 1981.

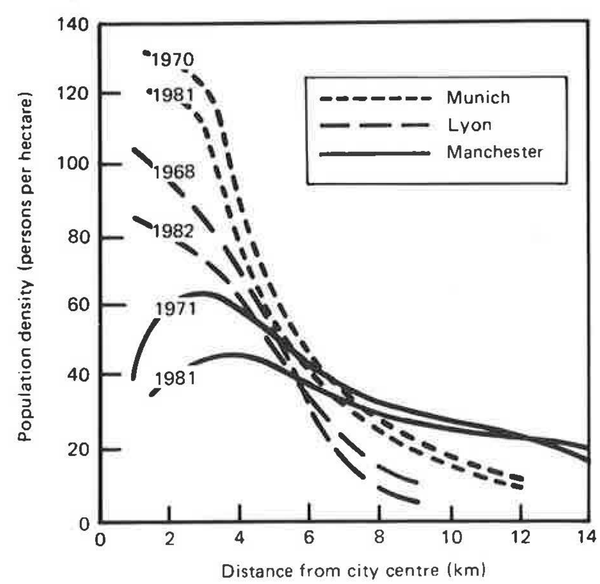

FIGURE 6 Changes in population density with distance from city center.

times that result from the lower service levels and sparser route networks in outer areas. In addition to this effect, waiting times on all routes (central and outer) in British cities are tending to lengthen as services are reduced in response to falling patronage—a trend that is not relevant to Continental cities where patronage is buoyant (Figure 4).

Movement of Population

In almost all developed countries there has been a drift of population from large cities to small towns over many years. Superimposed on this is the migration from rural areas to urban areas that is still continuing in some countries, particularly in southern Europe (urbanization ceased about 30 years ago in Britain). The net result of these changes is that many large Continental cities are still growing while the larger British cities and some of those in northeastern Europe are declining. Figure 5 shows how London peaked in the early 1950s and the main conurbations in the 1960s; medium-sized cities are approaching their peak at the present time, and smaller towns are still growing strongly. Public transport in many of the larger Continental cities is gaining patronage from the extra population, but in the United Kingdom the declining population of the larger cities is responsible for some loss of patronage. These losses are not canceled out by corresponding increases in patronage in the expanding smaller towns because people in smaller towns have less need for public transport.

In addition to these trends there is also a movement of population from inner to outer areas of practically all major cities; this is causing a general decline in built densities, especially in the inner areas, as shown in Figure 6. Because of the compactness of many Continental cities, a relatively high proportion of the inhabitants live close enough to workplaces, shops, and other facilities to walk or cycle to them. Population dispersion leads to a greater need for mechanized journeys, and although this encourages car use, public transport also gains, particularly if activities remain in the city center. Suburbanization in the United Kingdom in the first half of the century led to trip rates by public transport that were among the highest recorded anywhere in the world (they are still high despite many years of decline), but car ownership levels were low at that time. Any encouragement that suburbanization might give to public transport in the expanding cities of Europe will now be much smaller than it was in the United Kingdom because car ownership levels are high. Even though initial spreading can bolster public transport use, further dispersion will eventually result in suburban development that is more difficult to serve by public transport and more convenient for the private car, unless development takes the form of "beads on a string" (i.e., high-density settlements surrounded by "green" areas and connected by fast, frequent public transport systems, usually rail; Stockholm and Paris offer good examples of these systems). Thus in some cities the dominant forms of suburbanization are producing a clustered type of settlement pattern that might actually increase public transport use in spite of the dispersion of population and declining overall densities. In others, densities have fallen more uniformly and to relatively low levels, producing the amorphous suburbanization that greatly weakens public transport.

Changes in Employment

Many of the traditional manufacturing industries of the older cities are dying, leaving the inner city areas surrounding the central business districts (CBDs) of such towns with a diminishing number of employment opportunities. New industries, particularly service industries and high-technology manufacturing, are increasingly likely to locate in smaller towns, as the data in Table 1 indicate, or in the outer areas of larger towns where land is cheap and access to the national road network is good. When both the origin and the destination of trips are in the outer areas, the provision of an adequate public transport service becomes even more difficult and expensive than when only the population is dispersed, and the use of the car is made easier.

Service and retail employment is still largely centrally based and growing, but growth in the outer areas is proportionately greater than in the center, albeit from a smaller base. Although public transport stands to gain from this growth in the city center, it is generally not sufficient to counter the loss of trips caused by the reductions in the manufacturing industry in the area surrounding the CBD. On the whole, therefore, changes in employment location are tending to work against the use of public transport and in favor of the car, though the growth in service employment in some towns (e.g., Toronto) is so great that public transport use is still on the increase.

Modeling the Changes

In the ECMT study *(1)* a mathematical model was used to predict the changes in patronage that could be expected to result from the observed changes from one year to the next in real fares (F), vehicle-kilometers operated (K), number of cars registered nationally (C), national population (N), level of urbanization (U), and number of unemployed workers as a proportion of the population (J). The model form was

$$P = P_o F^{e_f} K^{e_k} N(N - \beta C) U^f J^h$$

where P_o, β, f, and h are constants and e_f and e_k are the elasticities of demand with respect to fares and vehicle-kilometers. The values of these constants were based on the results of statistical regression analysis of the data collected, but in some cases the values obtained from regression were modified in the light of other available information. Because no systematic pattern could be discerned in the statistical relationships estimated for each individual country (and, of course, some were not statistically significantly different from zero), the same values of the coefficients were used for all countries, except that β was varied with the level of car ownership *(1*, Appendix). Moreover, the fare and service elasticities (e_f and e_k) were given rather larger values than the short-term estimates to represent the longer-term impacts of changing fares and service; this was in line with other TRRL work on predicting the use of public transport *(5)*. The effect of urbanization, in particular, could be handled only in a quite crude way because of the lack of suitable data.

The difference between the estimated change and the actual change, averaged over the period 1970 to 1980, is the

TABLE 1 CHANGES IN TYPE OF EMPLOYMENT IN GREAT BRITAIN BETWEEN 1959 AND 1975 *(4)*

	Change as Percentage of Total Employment in Each Area in 1959				
	Agriculture	Mining	Manufacturing	Services	Total
London	−0.3	0	−13.0	+1.9	−11.4
Conurbations	−0.3	−2.4	−7.9	+5.9	−4.7
Free-standing cities	−1.0	−3.6	+1.1	+16.0	+12.5
Industrial towns	−1.4	−4.6	+6.9	+21.1	+22.0
County towns	−4.6	−0.1	+7.5	+15.2	+18.0
Rural areas	−6.5	−1.7	+11.1	+11.4	+14.3
Whole of Great Britain	−1.3	−2.2	−2.2	+10.8	+5.1

NOTE: In this table the change in each sector is expressed as a percentage of total employment in each area in 1959. For instance, in London the fall in manufacturing employment between 1959 and 1975 was 13 percent of all employment in London in 1959, but as a proportion of all manufacturing employment in London it was 38 percent.

"residual" trend: this is the unexplained part of the trend, representing the combined effect of factors that have not been considered in the calculations or the treatment of which is otherwise inadequate. The degree of explanation achieved is measured by the extent to which the residual trend has a smaller spread of values across the various countries than had the observed trend. There is, of course, considerable uncertainty in trying to account for the observed trends in this way, but the model was subjected to a range of sensitivity tests, and in general the relative residual trends for the different countries, and the width of their spread, were fairly stable to changes in the assumptions (*1*, Appendix).

Figure 7 shows the countries ranked according to the magnitude of the residual trends and the contribution of the individual factors to the explanation of the trends between 1970 and 1980. The standard deviation of the residual trends is 1.39 and that for the actual trends is 2.03. Thus it appears that the model is able to explain about one-third of the variation. In addition to these factors, however, those countries with a high absolute level of use show a more positive trend over time, other things being equal, than those countries with low use. When this aspect of the explanation is taken into account, it appears that more than one-half of the variation in patronage can be accounted for and perhaps three-quarters of that part of the variation that is likely to be explicable (bearing in mind the inherent variability of the data).

The ranking of the countries according to their residual trends appears tolerably plausible: for example, in Italy, Sweden, Germany, and Switzerland the actual trends are appreciably more positive than the assumed model would suggest, possibly because of heavier than normal use of rail, which may be more effective than bus services in retaining patronage in the face of competition from the car. In Italy the relatively fast growth of the larger cities, which was not adequately reflected in the overall measure of urbanization, has probably been partly responsible for the positive trend. At the other end of the spectrum are Australia, New Zealand, and the United States, which have favored an especially low-density form of suburbanization, which is particularly unsuited to the use of public transport. Thus the actual trend in these countries is lower than the model would suggest. Nevertheless, it is reassuring that so much of the variation in patronage trends can be explained by a model that assumes that various factors work at the same strength in each of the different types of countries included. It was also of interest that the residual trends for France, Britain, Spain, and Ireland were close to zero: in other words the patronage trend was almost completely explained by the mechanisms included and at the strengths assumed. Thus, compared with other countries, there are no special reasons that make provision of public transport in these countries either especially difficult or specially easy—changes in use are due to factors that appear to be working in all of the countries at much the same strength.

IMPLICATIONS FOR THE FUTURE

Table 2 gives a summary of the various factors that influence use of public transport or car, and it contrasts the situation in the United Kingdom, with its declining public transport trend, with that in may of the countries in Continental Europe. In the United Kingdom, all of the factors tend to work against public transport and in favor of increasing car use, whereas in many Continental European countries some of the factors still favor public transport. However, they will not continue to do so indefinitely. Urbanization is close to saturation, further reductions in density are likely to create the sort of dispersed suburbanization that encourages car use instead of public transport, and even the creation of high-density satellite settlements will not continue to bolster commuter rail if central-area employment declines or if people elect to live or work in a more

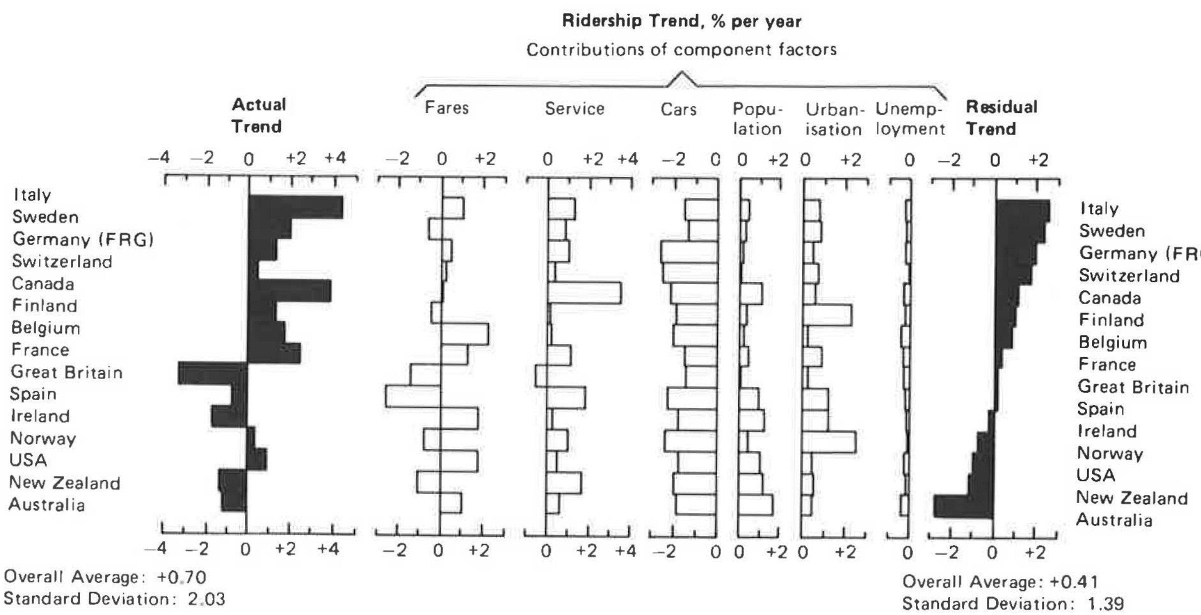

FIGURE 7 Estimated residual trends for national data (assuming fare elasticity of −0.45 and vehicle-kilometer elasticity of 0.45).

TABLE 2 EFFECT OF FACTORS THAT AFFECT TRAVEL

Factor	U.K.	Typical Continental Countries Short Term	Typical Continental Countries Long Term
Urbanization	–	y	–
Population dispersion	x	y(?)	x
High-density settlements	–	y	x(?)
Employment decentralization	x	x	x
Travel speed	x	x	x
Car ownership	x	x	x
Travel costs	x(?)	y(?)	x(?)
Transfer from two-wheeled to public transport	–	y	–

NOTE: y = favors public transport, x = favors car, – = no effect or N/A, and (?) = but could go the other way.

dispersed pattern. Transfer from two-wheelers is an important source of public transport patronage in some countries, but this reservoir too must eventually dry up.

Thus in the longer term, public transport use appears to be set to decline even in those countries where it is presently growing and where public transport policies might appear markedly successful. Adoption of the same policies in the United Kingdom would not produce the same level of growth because the favorable factors do not exist in the United Kingdom. Estimates have been made of the likely effects of reducing or withdrawing subsidy in the various countries, using the same assumptions about the elasticity of demand as were used in the trend analysis. Rising subsidies may have reversed a declining public transport trend in almost one-half of the 16 countries in the ECMT study. Only a quarter of these countries would have retained an upward trend in the absence of subsidy and there would have been passenger loss if subsidy had not been allowed to grow. If sufficient funds were available, reversal of the trend could be achieved in the United Kingdom too, but this cannot be a permanent solution: subsidies would have to be increased indefinitely to maintain growth, and the underlying decline would reassert itself as soon as no further increases were forthcoming. A similar boost to public transport use will be achieved if "deregulation" of bus services (under the 1985 Transport Act there are no restrictions, other than safety requirements, on setting up new bus services in the United Kingdom) is successful in reducing costs and making services more responsive to demand: while such improvements continue they will increase patronage relative to the underlying trend, but the fundamental changes in travel patterns described earlier will inevitably continue to reduce the total market in which public transport has to operate.

It therefore appears that long-term decline in public transport use has to be accepted in the United Kingdom and will probably have to be faced eventually even in countries where the prospects for public transport are currently much brighter, but this is not to suggest that public transport will disappear from the urban scene. The present rate of decline in the United Kingdom will slacken in the future as more newly acquired cars are second or third cars in the household. Forecasts using TRRL's bus prediction model *(5)*, shown in Figure 8, suggest that the total of stage bus journeys is likely to decline by perhaps one-quarter during the next 15 years, if the economy grows at 1.5 percent per annum, assuming present levels of subsidy and fuel prices rising 3 percent per annum over the longer term. On the other hand, if the economy grows at 2.5 percent per annum, encouraging higher car ownership and higher wages in industry, the decline could be as much as 40 percent. If deregulation could achieve an overall reduction of 20 percent in unit costs, the decline would be held to between 10 and 20 percent, depending on economic growth. Whatever the level of decline, services feeding city centers are likely to remain relatively strong, but people without a private car will find it increasingly difficult to get to noncentral destinations as peripheral services become more thinly spread. For people living in the outer suburbs (not all of whom by any means will have a car available) access to the center may be more difficult than it is today because of longer access distances and less frequent services on the outer parts of the public transport network.

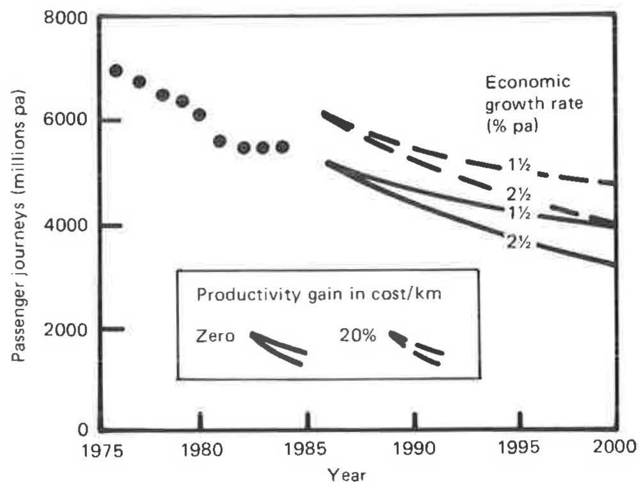

FIGURE 8 Future patronage levels on bus stage services in Great Britain under different assumptions of economic growth.

With increasing office automation, the number of jobs in the city center is likely to decline ultimately even if the total amount of business activity increases. With more floorspace per employed person, the central business district may look much the same as it does today, but the density of jobs will be less. The continuing decline of inner-area manufacturing industry in older cities will tend to increase the proportion of the unemployed, the old, and the disadvantaged in these areas as the young and more highly qualified members of society move out to take up the new, more highly skilled jobs that become available in outer areas and in smaller towns. This will weaken the already fragile financial base of some of these cities.

In contrast, cities with a broader economic base, particularly one that includes major financial institutions or new high-technology industry, will attract a disproportionate share of new jobs and young, economically active residents. Their centers are likely to thrive, but their very affluence will encourage expansion at lower residential densities, and their ability to sustain high-capacity public transport services is bound to diminish. If service-sector employment continues to grow faster in the outer areas than in the center, its distribution may ultimately follow the trend in manufacturing, so that the centers cease to grow and may eventually decline in service activities. The strength of public transport depends substantially on the continuing existence of a concentration of jobs and activities in city centers; if the centers decline, the implications for public transport, and for the structure of the city itself, could be serious.

POSSIBLE FUTURE URBAN STRATEGIES

The foregoing analysis suggests that there are strong underlying social, economic, and demographic trends that are causing changes in the quality of urban life and in the mobility of the different sections of the community and that it would be difficult, if not impossible, to preserve the status quo. Even if this could be done, the majority of the people would probably not be pleased with such a solution because the changes that are taking place are the direct result of these people's taking full advantage of their increased affluence to widen their opportunities and improve their living standards. The argument that rising car ownership is due to a way of life that compels people to own cars, and that if things were organized differently cars would be both unnecessary and undesired, is not convincing, given the similarity of the link between affluence and car ownership in all countries and environments. It appears that whatever problems mass car ownership may bring, they will have to be coped with.

Nevertheless, even the affluent section of the community will lose something as a result of the changes that are taking place: many people will miss the sort of urban social life that is only possible in thriving cities with strong centers that contain a large residential population. Those who always have a car available are not immune to the inconvenient aspects of a car-based life-style; some of them will be in households where for reasons of age or infirmity not all members can drive and they may find themselves acting as chauffeur to an undesirable extent. But it is the 30 percent or so of the population without access to a car who will suffer most from the effects of mass car ownership and urban decentralization, and it appears that the bulk of the effort in the future should be directed toward ensuring that the needs of this sizable minority are adequately met. There is also the danger that rapid change might bring about a waste of resources; buildings and infrastructure with years of remaining useful life might become obsolete. What can be done?

Unless serious thought is given to these issues and appropriate strategies developed in good time (many schemes have long lead times), it is likely that any measures will constitute little more than a rearguard action, with most of the trends continuing in much the same way as at present but with a few palliatives to ease the burden on those who are most adversely affected by the changes. There are alternative strategies, however, that are more appropriate to the changing situation:

1. Strategies that provide, either through redevelopment or with new construction, homes that are less dependent on the private car for access to jobs and everyday facilities and
2. Strategies that slow the rate of change of urban decentralization through positive incentives so that existing resources are used more effectively and there is more time for adaptation by both people and firms.

The first of these strategies can be achieved either with public-sector housing developments or through planning controls that affect private developments. It may take a variety of forms: one is to have areas of mixed development where residents can walk or cycle to workplaces, shops, or other facilities; another is to have compact areas of housing with good transport links to equally compact areas of workplaces, shops, and the like. Even where housing densities are not particularly high, appropriate planning can greatly increase the accessibility of the occupants to public transport services, as is the case in Runcorn *(6)*. If the areas are planned with concentrations of homes and facilities at sufficient densities to generate a high level of demand for public transport, services could be self-supporting (if need be), even though subsidy might be applied for social reasons. Residents may therefore feel secure in the knowledge that the continuation of their transport links does not depend on the willingness of the local authority to subsidies services or on the goodwill of those voluntary organizations that are being used increasingly to operate community bus services to meet the needs of people in low-density areas. Land use allocation and transport provision must be planned together from the outset for this strategy to work.

The second strategy involves ways of slowing down existing land use trends, particularly those that affect the strength of the town center because without strong centers it is difficult for good public transport services to exist. Attempts to slow these trends using highly restrictive measures (e.g., land use controls that severely constrict the developer's choice, or punitive taxation and pricing measures that affect the location or transport decisions of people and firms) may well be counterproductive in the long term as people and firms exert their right to locate where they wish to be and to travel to destinations of their choice. If one town does not provide the required choice it is likely that another one will.

Prohibitive controls are likely to be successful only if the alternatives they are supposed to encourage (whether these are development forced into alternative locations by planning restrictions or travel forced onto alternative modes by pricing restraints) are sufficiently attractive for people to use them not merely in the short term but also in the years ahead. Some "negative" or prohibitive controls, however, are bound to be necessary if a free-for-all situation is to be avoided, but where possible it is better to employ positive incentives, relying on the "carrot" rather than the "stick."

Making the town, and particularly the town center, more attractive will encourage existing firms to stay (and possibly to expand) and will attract potential developers. It is likely that measures that are successful in retaining employment will also be successful in retaining people, especially the young and more economically active. The process is self-reinforcing: successful towns tend to attract more people and businesses and achieve greater growth, and declining towns increasingly lose their attraction as people and businesses depart. There is also a negative feedback element, however; the more successful a town center is the more likely it is to have congestion, parking difficulties, higher rents, and so forth, which, if left unchecked, will eventually slow down the town's growth. This may not be viewed as necessarily undesirable in those cases in which there are advantages to channeling further growth into other towns.

In most cases, however, these problems will be tackled using the usual remedies of new road construction, provision of extra parking spaces, and improvements in public transport (new metro systems, provision of bus lanes, better services, etc.).

The optimum balance between improvements in public transport and improvements in the road network depends on the extent to which people with a car available are likely to forgo the use of the car and use public transport instead to gain access to town-center activities. This in turn depends on both the attractiveness of town-center destinations and the quality of public transport. High quality in just one of these aspects is generally not sufficient to entice drivers from their cars; both are normally necessary. Thus, in towns that are declining, provision of costly new transport infrastructure may fail to attract new users in sufficient numbers and the investment may only serve to accelerate the decline if it places additional financial burdens on an authority that is already in financial difficulty. In these towns, however, lower congestion, easier parking facilities, and lower rents can be used as bait to attract new development, provided redevelopment can be done on such a scale that it is not devalued by any remaining dereliction. Sensitive redevelopment, which accepts the desire for lower densities and use of the car where this is appropriate and makes the best use of any natural features, such as rivers, canals, hills, open spaces, and buildings of architectural or historical merit, has been markedly successful in many cases. Such improvements are unlikely to reverse the outward movement of people and jobs but may at least slow down the exodus to manageable proportions while creating a much more pleasant environment for those who remain.

Redevelopment on the scale suggested here requires a combination of comprehensive planning, involvement of the private sector, and channeling of market forces because urban economics tend to be governed by the large scale of private rather than public investment. Such redevelopment requires that inner-city land not be overpriced because of historic "book values" (otherwise private developers will be frightened off) and that developable land be put together in sufficiently large parcels, despite the institutional problems, for the plans to be carried through at a reasonable pace. If attempts at redevelopment are too long delayed, the exodus of people and jobs will make renewal even more problematic, especially because it is the more active and affluent members of the community who are also the more mobile.

CONCLUSION

Urban travel patterns are changing, and factors that encourage the use of the private car are likely to remain important into the foreseeable future, with an increasing share of travel taking place in noncentral areas and in smaller towns. Conversely, those factors that presently favor public transport use in some countries are likely to diminish in the longer term so that there, as in the United Kingdom, public transport use appears to be about to decline.

Increasing subsidies can combat this trend but only at an ever-increasing cost, and the decline would reappear as soon as subsidy stopped increasing (reductions in operating cost would also boost public transport use but would only raise the level from which the decline occurs). The mechanisms underlying the decline are connected with changing patterns of land use and urban development, and these are so fundamentally tied to increasing affluence and car ownership, and to industrial reorganization, that it is neither feasible nor desirable to reverse them. It is more realistic to acknowledge that the size, function, and structure of cities are bound to change and to accept the dispersion of people and jobs away from large towns as an opportunity to redevelop the inner areas in a way that is compatible with people's requirements for more space and more mobility. Integration of the planning of land development and transport facilities can improve the mobility of people who do not have access to a private car, and, if necessary, financial support can be channeled into those areas where it is most needed, either to support extra transport services or to catalyze redevelopment more suited to the new conditions.

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REFERENCES

1. F. V. Webster, P. H. Bly, R. H. Johnston, N. Paulley, and M. Dasgupta. *Changing Patterns of Urban Travel.* Report to the European Conference of Ministers of Transport. OECD Publications, Paris, 1985.
2. *World Road Statistics.* International Road Federation, Geneva, Switzerland, annual.
3. R H. Johnston. *Travel Characteristics of Seven French Cities.* TRRL Report LR 1106. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1985.
4. S. Fothergill and G. Gudgin. *Unequal Growth: Urban and Regional Employment Change in the UK.* Heinemann, London, England, 1983.
5. R. H. Oldfield, P. H. Bly, and F. V. Webster. *Predicting the Use of Stage Service Buses in Great Britain.* TRRL Report LR 1000. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1981.
6. R. A. Vincent, R. E. Layfield, and M. D. Bardsley. *Runcorn Busway Study.* TRRL Report LR 697. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1976.

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Comparison of Interactive Land Use and Transport Models

P. H. BLY AND F. V. WEBSTER

Changes in transport are likely to produce changes in land use, and these long-term effects of transport policy may be of considerable potential importance. Ultimately, progress in estimating and predicting these effects will depend on the development of reliable, quantitative models that embody two-way interaction between land use and transport. During the past decade or so a number of such models have been developed and have been used for policy testing and planning. Validation of these models is difficult because of the long time scales over which their mechanisms operate, and the Transport and Road Research Laboratory has initiated an international collaboration of seven countries to try to assess the plausibility of nine models by a comparative analysis of their structure and performance. The first phase of this study is now almost complete, and the International Study Group on Land-Use/Transport Interaction is about to publish its report in which the methodologies of the models are discussed and their behavior is compared when applied to a set of more than 40 standardized tests involving changes in population growth and composition, changes in the distribution of employment and shops, changes in travel costs and the transport network, and different sequences of transport investment. This paper contains a description of the study, a brief review of the models, discussion of results from a handful of the tests, and some general comments on the findings.

The need for models for use in predicting and assessing the outcome of transport policies and investment is generally accepted, and a wide range of models is in routine use. The end users of the information produced by the models may sometimes have reservations about how reliable it is likely to be, but by and large they accept that there is no alternative to modeling for providing quantitative estimates of the outcome. The four-step transport model, in particular, is used universally. This takes the pattern of land use as given and predicts from it how much traffic will be generated, which destinations it will go to, what modes it will choose, and which roads or rail lines it will use. Yet looking back on the history of urban development it is clear that not only are travel patterns dictated by land use but that, on a longer time scale, changes in transport have in their turn had a profound effect on land development. Indeed, this two-way interaction is often explicit in transport investments aimed at "opening up" or "revitalizing" areas considered ripe for development.

Thus if modeling is to predict the ultimate effects of transport policies, it cannot take land use as an exogenous input. The effects on land use may take a long time to appear fully, because urban development and renewal generally take decades rather than years, but they will inevitably modify the initial outcome of transport policies or investment, and in some cases the long-term effect could conceivably be quite different from the short-term effect. Planners are aware of this in a general way, of course, but the mechanisms involved are complex and inherently difficult to isolate and measure because the long time scale causes the effects to be obscured by the many other changes that occur in urban systems. Naturally, individual experience and expertise count for much, but without some framework on which to assemble knowledge of this sort it remains fragmented and is difficult to transfer to other situations or to other individuals. Progress in estimating these effects in a rational and quantitative way must depend ultimately on the development of such a framework, and part of this will consist of models that embody the two-way interaction between land use and transport.

This type of modeling received considerable attention during the 1960s. Lowry's Model of Metropolis *(1)* is generally regarded as the foundation of integrated land use and transport models, and this theme was quickly elaborated to provide more detailed descriptions of both the land use and transport sectors. Unfortunately, these first skirmishes with the problem ended in general disillusionment with large-scale computer modeling in the 1970s; the disappointment with, and criticism of, these models is well documented in papers by Lee *(2)*, Pack *(3)*, and Sayer *(4)*. This was largely a result of modelers trying to run before they could walk properly. They promised too much and failed to deliver. But in part the fault lay also with the users, who did not understand the limitations of an as yet undeveloped methodology and expected the models to provide answers beyond their capabilities. A few well-publicized failures produced a climate in which planners and other potential users looked askance at any newly developed large-scale model, however well it may have overcome earlier problems.

This climate appears to be improving; those who have to make decisions appreciate the need for guidance from whatever sources are available. If they ignore the potential usefulness of coherent, integrated, and rational models, decisions will be made on the basis of personal mental models embodying assumptions that are certainly no more clearly stated, better tested, more compatible, or less partial than those of the urban modelers. It is hoped that both modelers and users now have a clearer appreciation of the difficulties and limitations of modeling and understand the usefulness of models as tools to aid understanding rather than as all-powerful determinants of the "right" decision.

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PRESENT STUDY

There is no satisfactory alternative to some form of modeling, yet the modelers will readily admit that there is ample room for improvement in present modeling practice. Improvement can only come from assessing the models against reality. It might be noted that this has all too rarely been done with conventional transport models, but validation of the integrated land use and transport models is made especially difficult by the long time scale of the land use response. Much effort and money have gone into producing such models, and several of them have been used seriously to examine a number of policy questions. If planners and decision makers are to use the most appropriate models, they need to know what is available, how well-suited the models are to particular situations, and how reliable their predictions are likely to be. More generally, they can also make use of these models to understand more about the likely impacts of different policies in order to select broad urban strategies. The specific measures by which these strategies operate can then be tested using the most appropriate model. To provide this advice, in 1981 the Transport and Road Research Laboratory initiated the International Study Group on Land-Use/Transport Interaction (ISGLUTI), with the twin aims of

1. Providing a rigorous program of comparative testing of available models and
2. Assessing the impacts (and especially the longer-term impacts) of the more commonly used land use and transport policies.

The study group includes researchers from eight countries with nine operational models (Table 1). The data in the table indicate the length of experience of the modelers with this type of interactive model, though in most cases the model used in the ISGLUTI study is a much developed version, or an entirely different formulation, from the initial model constructed at the date shown.

The program of work has been developed to provide results in consecutive phases. Phase 1 of the study is the least ambitious, though it has nevertheless proved to be a difficult and substantial achievement. Each model has been applied to an agreed series of "standard" tests. In all, 43 tests were formulated in several different categories dealing with effects of population growth, changes in the distribution of employment and shopping, changes in transport costs and travel speeds, impacts of roads and metro lines, changes in car ownership and effects economic recession, and effects of introducing transport investment and public transport subsidies in different time sequences. Naturally, with limited resources available, it has not been possible for all of the modelers to carry out all of the tests, but to date the study has results from 158 combinations of models and tests, and three of the models, DORTMUND, LILT,

TABLE 1 PARTICIPANTS IN THE ISGLUTI STUDY

Group Members	Organization	Name of Model and Year First Developed	Model Code	City Modeled
J. Brotchie J. Roy R. Sharpe	Commonwealth Scientific and Industrial Research Organization, Australia	TOPAZ 1970	T	Melbourne
M. Wegener	University of Dortmund, Federal Republic of Germany	DORTMUND 1977	D	Dortmund
G. Giannopoulos M. Pitsiava	University of Thessalonika, Greece			
K. Amano T. Toda H. Yamanaka	University of Kyoto, Japan	OSAKA 1981	O	Osaka
H. Nakamura Y. Hayashi K. Miyamoto	Universities of Tokyo and Nagoya, Japan	CALUTAS 1978	C	Tokyo
H. Floor T. de Jong	University of Utrecht, Netherlands	AMERSFOORT 1976	A	Amersfoort
L. Lundqvist	Royal Institute of Technology, Sweden	SALOC 1973	S	Uppsala
R. Mackett	University College, London, United Kingdom	LILT 1974	L	Leeds
M. Echenique A. Flowerdew	Marcial Echenique and Partners, United Kingdom	MEP 1968	M	Bilbao
V. Webster P. Bly N. Paulley	Transport and Road Research Laboratory, United Kingdom			
S. Putman	University of Pennslyvania, United States	ITLUP 1971	I	San Francisco

and MEP, have been able to complete the great majority of the tests. An analysis of the behavior of the models, a comparative assessment of model structures, and the main findings of applying particular urban policies will be published shortly in the first report of the study.

In this first phase, the tests have been completed using the models as calibrated on their own base data, so that for each model the results relate to a different city. This was a practical way to proceed, but of course it complicates the comparisons because it is not clear whether differences in the results are due to differences in the models or to particular characteristics of the cities to which they were applied. It is hoped that the questions raised by this extra complication will be answered in a more ambitious Phase 2, which requires the transfer of models between data sets so that the behavior of several models can be judged using the same data base for each and the effect of different city types can be assessed separately by comparing the behavior of a given model across several different data sets. This work is well under way, and so far there have been nine transfers of models from one data base to another, with a maximum of four different models recalibrated to one city data base and a maximum of four cities represented by one model. This phase of the study will be reported in 1988.

All testing of the models is restricted to assessing one model against the others and judging the general plausibility of their behavior. The ultimate test, of course, is to compare the long-term predictions of the effects of some major transport change with long-term observations of what actually happened. It is possible that such an exercise might constitute a future Phase 3 of the study, but the possibility of doing this depends on the availability of satisfactory before-and-after data sets, across a sufficiently long period, that contain a transport change that is sufficiently large to produce land use effects that are unambiguously identifiable against a constantly changing background. This is a demanding set of requirements and so far no satisfactory case has been identified.

MODELS

Because the models are intended to examine much the same aspects of transport and urban development, it might be thought that they would be fairly similar in construction. Certainly, they all operate by dividing the area they represent into discrete zones and allocating to each zone units of activity (people, housing, jobs) in a way that depends on the accessibility of that zone to other zones as well as on the inherent attributes of the zone itself. They all proceed through time by estimating changes in land use patterns and travel between one time point and the next (in 5-year intervals, in most cases). Beyond these quite broad characteristics, however, comparison of the structure of the models provides an impression of considerable variety rather than of similarity. It would be inappropriate to discuss these comparisons in detail here, but it will be helpful to give a brief description of the main characteristics of each model. Table 2 gives a summary of these, though the reader will appreciate that in imposing these standardized descriptions this brief review omits much interesting detail. Moreover, in some cases the form of the model used in ISGLUTI has a coarser categorization or spatial representation, or both, than is present in other versions; this applies especially to ITLUP, MEP, and TOPAZ.

The overview given here does no more than sketch the most important features of each model. The ISGLUTI report will provide a detailed comparative discussion of the theories and mechanisms underlying each model, the ways in which they allocate land use, the form of their transport models, and the built-in interactions between transport and land use. The report will include an examination of the calibration and validation of the models, the form of their data bases, the types of output they provide, and their computing requirements. It will also provide brief descriptions of the ways in which these models, and variants of them, have been applied. All of these models are fully operational, all have been used to examine genuine policies, and all except DORTMUND and OSAKA have been transferred to other data bases. Some have been used quite extensively indeed: MEP models have been applied to 17 different cities or areas, ITLUP to 10, and TOPAZ to 7. It can be seen from Table 2 that, as a group, the models have been designed to represent a wide range of city sizes (from the 28 million population of Tokyo to 150,000 in Amersfoort) and cultural backgrounds; they operate at quite different levels of detail; and they embody a considerable variety of theoretical underpinning and modeling techniques. Some of these differences make comparison more difficult, of course, but the study provides an amply wide scope for assessing the strengths, weaknesses, and range of applicability of this type of modeling.

AMERSFOORT

This is a relatively simple model that follows the original Lowry model in locating population relative to employment via an entropy-maximizing form of the gravity model, but it does not locate employment endogenously at all (though later versions have located shopping). Instead it relies on exogeneous forecasts of total employment and its location. Unlike some of the more complicated models, however, it makes a distinction between the distribution of housing and the location of population, so that houses may remain empty and the social grouping of their occupants may change. The different social groups have a hierarchical choice of housing, so that the more affluent have a freer choice. Travel impedances are represented only by interzonal distances, so that the model predicts the pattern of travel to work but provides no detail about mode use, times, or costs. Because of this simplicity, the model's data and computing requirements are quite modest, and transfer from one data base to another is correspondingly easy. A detailed description can be found in Floor *(5)*.

CALUTAS (Computer-Aided Land Use–Transport Analysis System)

This utility-based model calculates a "locational surplus" of utility minus cost to determine where both population and employment will locate and to produce estimates of land prices. Employment is categorized in some detail, but population is not, though the present version of the model separates

TABLE 2 MAIN CHARACTERISTICS OF THE MODELS

	Model								
	A	C	D	I	L	M	O	S	T
Model type (predictive or optimizing)	P	P	P	P	P	P	P	O	O
Modeling techniques used[a]	E	E,U,M,R	E,U,M,C,S	E	E,U,C	E,U,M,I	U,M,S,R	U,P	E,P
Land use location[b]									
Population	3	1	30	4	3	4	1	2	1
Housing	1	–	30	–	1	**	–	–	–
Employment	–	10	40	4	12	5	17	–	1
Workplaces	–	–	40	–	12	**	–	–	–
Land prices		√	√			√	√		
Housing rents			√			√			
Transport representation									
Trip pattern	√	√	√	√	√	√			√
Number of purposes	1	5	4	2	5	4			4
Number of modes	1	2	4	2	3	3			2
Traffic congestion		√	√	√	√	√			
Predicts car ownership			√		√				
Data base									
City represented	Amersfoort	Tokyo	Dortmund	San Francisco Bay Area	Leeds	Bilbao	Osaka	Uppsala	Melbourne
Population (000s)	153	27,904	1,075	4,064	497	970	14,556	160	2,697
Area (km^2)	202	14 565	833		164	75	8000		3000
Number of zones	26 (12)+	76 (14,500)++	30	30	28 (12)+	28	40 (840)++	49	41

NOTE: – = not represented; √ = item is represented; + = external zones to handle in- and out-commuting; ++ = two-level zonal hierarchy: larger number of zones at lower level offers greater spatial detail; ** = supply of accommodation is represented by available floor space, for which the different categories of demand compete.

[a]E = spatial interaction models, mostly of entropy-maximizing Wilson Types 1, 2, 3, and 4; U = utility maximizing models; M = market equilibrium models; C = Cohort/Markov survival models; I = input-output economic base models; S = microsimulation; R = linear regression models; P = mathematical programming.

[b]Numbers refer to number of categories used, where appropriate.

household types by composition. Housing is not distinguished from population, so it is assumed that the supply of buildings is identical to the demand. In addition to travel between home and work, the travel model represents trips for shopping, education, and "other purposes," and non-home-based trips on public and private modes and takes account of the effect of traffic congestion on road speeds. To represent a vast metropolitan area at an adequate level of detail, the model adopts a two-stage approach: it allocates activities to 76 large zones and then reallocates the total activity in each large zone to a lower-level system of kilometer-square zones. This produces a remarkably fine level of spatial detail, though there is no feedback to the coarser aggregation. A detailed description can be found in Nakamura et al. *(6)*.

DORTMUND

This model is not very detailed spatially, but it is extremely detailed in other respects, with many different categories for population, housing, employment, and workplaces. Like AMERSFOORT it makes a distinction between the housing and the people who live in it (which many of the models do not), but it also distinguishes between employment and the buildings in which the workplaces are established. Its structure embodies a wide range of modeling techniques, and various simulation procedures represent the aging of both population and buildings and estimate the profitability to developers of conversion, demolition, and new construction. Thus the model predicts both land prices and building rents. The transport model is similarly detailed, representing travel for four different purposes by car, bus, rail, and walking, and using capacity-constrained assignment to represent the effect of congestion on road speeds. The model also predicts car ownership on the basis of household budgets and travel costs, so that changing conditions will affect car availability. A detailed description can be found in Wegener *(7)*.

ITLUP (Integrated Transportation and Land-Use Package)

ITLUP has quite a long history. It was developed initially from the PLUM and IPLUM models of the San Francisco Bay Area *(8)*. It incorporates the residential location model DRAM, which has been used extensively separately from the package, and the employment location model EMPAL. It is based on Lowry-like mechanisms for generating population from basic employment, and service employment from population, and for locating population in relation to employment. The location of employment differs from the Lowry approach, however; it uses a combination of extrapolations of past trends, interindustry accessibilities, and accessibility to workers. It operates at a medium level of categorization of activities and offers travel predictions for public and private modes, for work and shopping trips, and with capacity-constrained road assignment. Although the ISGLUTI application uses relatively few zones to cover this large area, in other applications as many as 290 zones have been used. A detailed description can be found in Putman *(8)*.

LILT (Leeds Integrated Land-use/Transport Model)

This is essentially a Lowry-type location model coupled to a four-step transport model, using a population location mechanism that allows the different social groups a hierarchical choice of housing. It distinguishes between demand and supply of both housing and employment, so that housing and jobs can remain vacant and houses can be demolished or overcrowded. It provides a medium to high level of detail in its categorizations, and the travel model offers car, bus, and walk modes for the same five trip purposes used in CALUTAS and a congestion-constrained road network. This and DORTMUND are the only models that predict car ownership levels as responses to travel costs. A detailed description can be found in Mackett *(9)*.

MEP (Marcial Echenique and Partners)

This model of Bilbao is one of a whole family of models that have been developed by Marcial Echenique and Partners and applied to a large number of cities around the world. The basic employment–population–service-employment iteration of the Lowry model is retained, but the interactions among the various employment activities and population are governed by input-output matrices. The supply side is represented by provision of floor space, which may be occupied at variable density and for which the different population categories and some categories of employment compete. A market equilibrium mechanism reconciles demand with supply and produces estimates of both land prices and housing rents.

Generally the model operates at a medium level of detail, but the transport networks are particularly detailed, representing travel for shopping, education, and other purposes in addition to work trips. A hierarchical modal split between car and public transport and then between bus and rail is used. Both public and private networks are capacity constrained, and car ownership is a function of income in the four social groups but not of transport costs. Much attention has been paid to an economic assessment of both land use and transport changes in the model. A detailed description can be found in Geraldes et al. *(10)*.

OSAKA

This model is faced with a problem that is similar to that faced by CALUTAS: trying to represent an enormous metropolitan area. It uses a similar hierarchical zoning system, with 840 zones at the lower level. It adopts the Lowry procedure for generating population from employment, but its allocation mechanisms depend on linear regression relationships that, at the lower level, produce land price estimates. Allocation depends on zonal accessibilities calculated from travel times by car and rail in quite a detailed way, but it is essentially a land use model and does not attempt to predict travel patterns. Employment is categorized in some detail, with different formulations for the interactions among the categories. A detailed description can be found in Amano et al. *(11)*.

SALOC (Single Activity Location model)

So far, all of the models described have been predictive in the sense that they purport to predict the likely outcome of imposing a specified set of conditions. The remaining two models in the study have an entirely different philosophy. They are optimizing or normative models in the sense that they determine land use patterns that are optimal relative to a specified objective. The concept of SALOC, in particular, is quite different from that of the other models—so much so that the ISGLUTI program of tests was not really appropriate to this model and a supplementary investigation was undertaken instead. The model estimates where additional population (or housing, but not both because it deals with a single activity) should be located to optimize a multiple-objective function representing local planning policy. In the Uppsala application the generalized cost (time and money) of access to work is traded against the infrastructure costs of sewerage, water, and education facilities and the desirability of keeping communities self-contained as far as possible.

Density constraints are applied to the new development. Mathematical programming techniques enable the model to sketch out rapidly a whole range of housing allocations that satisfy the objectives and identify those solutions that keep a maximum number of good options open for the longer-term future when the prevailing conditions may change. The model does not locate employment, which must be input exogenously, nor does it make any explicit representation of travel patterns, though the estimates of accessibility are based on a public-private modal split model. A detailed description can be found in Lundqvist and Mattsson *(12)*.

TOPAZ (Technique for Optimal Placement of Activities in Zones)

This is another optimizing model that uses mathematical programming to locate both population and employment. In this case the allocation minimizes the sum of travel costs and infrastructure costs for development subject to density and other planning constraints. It provides relatively little categorization in its ISGLUTI version, though other applications have provided much greater detail. It is coupled to a conventional, and moderately detailed, predictive travel model with public and private modes and travel for shopping, other purposes, and non-home-based trips in addition to work journeys. Its structure is such that it can be applied to most of the tests in the ISGLUTI program, but the optimizing nature of its locational mechanisms requires a different interpretation of the results from those of the predictive models because it is describing a land use pattern that best meets the stated objective, not necessarily one that is likely to be produced by the prevailing forces. A detailed description can be found in Brotchie et al. *(13)*.

COMPARISONS OF MODEL BEHAVIOR

As noted earlier, the study contained a program of more than 40 tests. Clearly, it is not possible to give more than a sample of the results obtained from this large program. At the time of writing, analysis of the results is still continuing, so it would be inappropriate to attempt to summarize the findings. Instead, it will have to suffice to provide a brief glimpse of the sort of results obtained by examining a few examples.

Naturally, the models were designed with a specific application in mind, and they were originally organized to produce output appropriate to that application. Consequently, they provided quite disparate sets of outputs, with relatively little common ground for comparison. It was necessary for ISGLUTI to specify a set of "standard" indicators and to modify each model to produce as many of these as possible in a standard format on magnetic tape. This often required considerable aggregation: where appropriate, population categories were collected into three social or income groups; employment into retail, non-retail-service, and nonservice categories; modes into public and private; and so on. One of the most important, and most difficult, aggregations was the comparative representation of land use patterns. The modeled areas were divided into three concentric aggregations of zones, labeled central area, inner suburbs, and outer suburbs. This division was rather subjective and not entirely satisfactory, but by examining the proportions of population or employment in each area it was possible to say whether a particular test encouraged more or less centralization of land use.

Not every model was able to provide every standard indicator, or course, but with a maximum of 94 indicators from each test for each model there was a large amount of data to analyze. The whole process of organization and presentation was computerized so that a range of tabulations and diagrammatic comparisons could be produced, at a greater or lesser level of detail, on request.

Because each model represented a different city, the effects of the tests had to be judged relative to different background trends in each case. Consequently, the estimated land use patterns and travel characteristics at the end of the 20-year forecast period starting at the base calibration year were compared not only with the situation in the base year but also with the "most likely future" situation at the end of the 20-year period. For the predictive models the latter is the base or "do nothing" forecast, which assumes that the prevailing conditions will continue to change in line with present trends, that present policies will continue, and that development and investment will be consistent with existing plans. For the optimizing models, the test results are compared with the optimum configuration under the conditions "most likely" to prevail in 20 years' time.

So far, no test results have been obtained from ITLUP and SALOC, though it is hoped that some will be available shortly. Other models completed only a portion of the tests, to which a higher priority had been attached. Even if a test has been completed, many of the standard indicators may not be available from some models. Consequently, comparisons of behavior have to be made across different subsets of the models for different indicators and different tests.

A brief illustration of the findings from three tests is presented in the following subsections. In the first two the effects of changes in travel speeds and costs, respectively, on land use patterns are examined. In the third the effects of redistributing employment are considered.

Example 1: Speeds of All Mechanized Modes Increased by 20 Percent

Historically, the impact of mechanized transport on encouraging urban dispersion is clear. Growing car ownership is still increasing the travel speed available to people on average, and in some cities improvements in public transport are also providing higher average speeds, though the changes today are proportionately small compared with the increases that mechanized transport initially offered compared with walking. The global change considered in this example is more of a sensitivity test than a specific policy, though, of course, investment in both road capacity and public transport infrastructure and services could increase travel speeds across the board. Interpretation of this test was fairly straightforward in most models; generally a 20 percent increase in line-haul speeds results in a much smaller percentage decrease in the generalized costs of travel, and for this reason the effects of the test were likely to be intrinsically smaller in most models than in OSAKA, where the interzonal accessibilities were based primarily on travel times, and in AMERSFOORT, where the test was interpreted by reducing the effective interzonal distances, which acted as travel impedances, by the full 20 percent.

Naturally, these changes in speed cause changes in the travel patterns in much the same way as would be shown by any conventional transport model (though the size of the changes will be modified by the responsive land use). Thus there are a general increase in average trip distance and a shift from car to public transport because the logit form of the modal split function encourages a shift toward the slower mode. Average journey time declines, but average money cost per trip increases because of the extra distance, except in TOPAZ where the shift to cheaper public transport outweighs this effect. Both DORTMUND and LILT predict a slight reduction in car ownership: in the former model because the higher cost of the longer journeys leaves less money in the travel budget for car ownership, in the latter model because of the net shift to public transport. Both of these models also show a shift from walking to both public transport and car, as would be expected.

Thus the models are in general agreement about the direction of the transport effects, though the absolute sizes of the changes vary somewhat from one model to another. Of more interest in these interactive models, however, are the changes in land use. These are represented in Figure 1 by the changes in the proportions of population and employment in the outer suburbs (as defined for ISGLUTI). It can be seen that these proportions have grown over the 20-year period of the base forecast, as all the cities modeled have become decentralized in both population and employment. The optimizing model TOPAZ shows no appreciable effect of the higher speeds in the test (T) because locational distributions that minimize travel costs do so at any level of unit cost. The other models show that higher speeds encourage more rapid decentralization of population as the outer zones become relatively more accessible. The effect is quite small in DORTMUND (D) and LILT (L), which are based on cities with negative or zero population growth, respectively, so there is relatively little expansion in housing compared with the other cities. Much larger effects are seen in AMERSFOORT (A), CALUTAS (C), MEP (M), and OSAKA (O), where the cities are growing and so are able to take more advantage of the higher speeds.

Movement of the population is constrained by inertia in the allocation of available housing in AMERSFOORT, DORTMUND, LILT, and MEP, which all distinguish between population and housing, but within the distribution of housing Figure 1 shows that the movements of the different social groups are generally larger than that of the population in total. In particular, AMERSFOORT and LILT show the bottom social groups (SG3) remaining relatively more centralized than in the base forecast, in contrast with the movement of the other social groups. In these models the bottom social group has last choice of housing because of the economic "pecking order" and tends to get pushed out of the more spacious outer suburbs as the higher social groups disperse further.

Figure 1 shows that employment also becomes relatively more decentralized when speeds increase in CALUTAS, MEP, and OSAKA. AMERSFOORT does not locate employment. LILT shows a centralizing tendency because, in this model, employment location appears especially sensitive to the quality of public transport. Given the largely radial nature of the public transport network, it is plausible that it would tend to focus activity in the city center, but this effect is certainly much more marked in LILT than in the other models. DORTMUND shows a similar tendency for service employment, but there is little effect on employment overall. In this test, and in general across all the tests, retail employment is most responsive to transport changes (and to shifts in the distribution of population) and nonservice employment least responsive, though OSAKA shows a similarly strong response in all employment categories. Indeed, OSAKA's accessibility-based location mechanisms appear to operate at much the same strength across both employment and population. OSAKA and LILT show the strongest response to the speed change (though in opposite directions), CALUTAS and MEP a weaker one, and DORTMUND the weakest response of all overall.

In MEP's economic assessment the higher speed produces a sizable net transport benefit, as would be expected, but there is little net land use benefit in line with the small changes seen in overall land use, though there is a slight increase in land prices

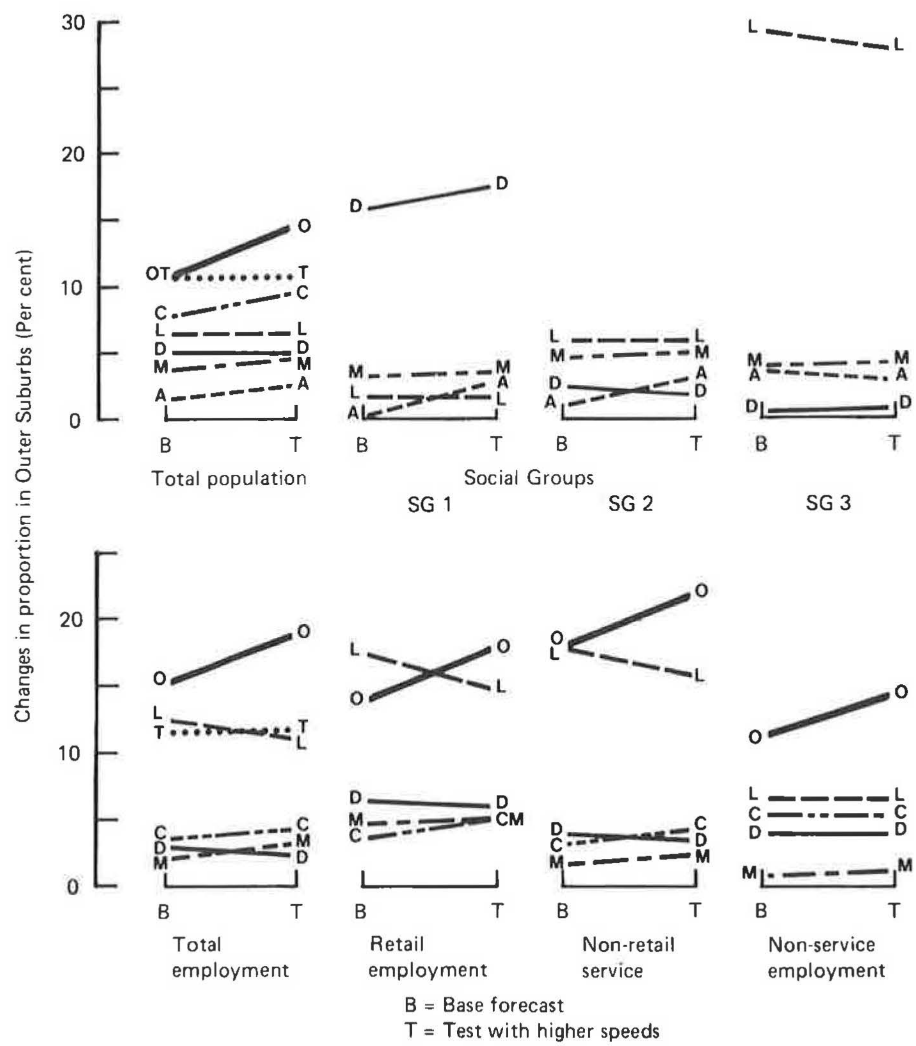

FIGURE 1 Changes in distribution of population and employment when speeds of mechanized modes are increased 20 percent.

on average. CALUTAS predicts a 15 percent rise in land prices, because the improved accessibility increases zonal locational utilities, and a marked land use benefit. DORTMUND suggests little change in land prices but a 3 percent increase in housing rents.

Overall, the effects of the 20 percent increase in speed are more or less as expected on the transport side, and the land use effects are also quite plausible, though there are some differences of detail that may be a function of the different city bases as much as of the different model structures. The land use effects are generally quite small, except in Osaka and in employment location in Leeds. In these cities, the interactive models suggest effects that are different in some important respects from those that a purely transport model would predict. In the other models the overall land use changes are small, which might suggest that in these particular cases there was less need to use an interactive model. Nevertheless, within these relatively unresponsive land use patterns overall, there are substantial movements in some individual sectors of the population and employment, and at a more disaggregate spatial level there are also larger movements than are evident in the extremely aggregate comparisons used in the study.

Example 2: Large Increase in the Cost of City Center Parking

This test required that car parking charges in the central area be set at three times the average cost of travel for car trips to the area. Because in all cases the average parking charges in the base were appreciably less than the average travel cost, this represents a fairly punitive increase. This test has been completed only by DORTMUND, LILT, MEP, and TOPAZ.

Naturally, the main effect of the test is to discourage trips to the center areas, as Figure 2 shows, and to encourage a more dispersed pattern of destinations. In LILT this diversion of trips is sufficiently large, particularly for work trips, to offset entirely the effect of the high parking charges on the cost of the average journey, but other models show the expected net increase, especially in DORTMUND despite the appreciable transfer from car to public transport and reduction in average trip distance. Changes in average trip time are small in all cases.

The generally small effect this test has on modal split may appear surprising, but it stems from the diversion of trips away from the center. This in turn is reflected in, and is in part a consequence of, a relative reduction of employment in the central area and a displacement toward the outer suburbs, as shown in Figure 3. The effect is especially marked in LILT and TOPAZ, with a smaller response in MEP, and very little effect in DORTMUND. The result for TOPAZ contrasts with its unresponsiveness in the previous test: the large cost changes in the central area are sufficient to discourage locating any more employment there. DORTMUND actually shows a relative centralization of service employment, partly because the shift to public transport focuses the travel pattern on the center

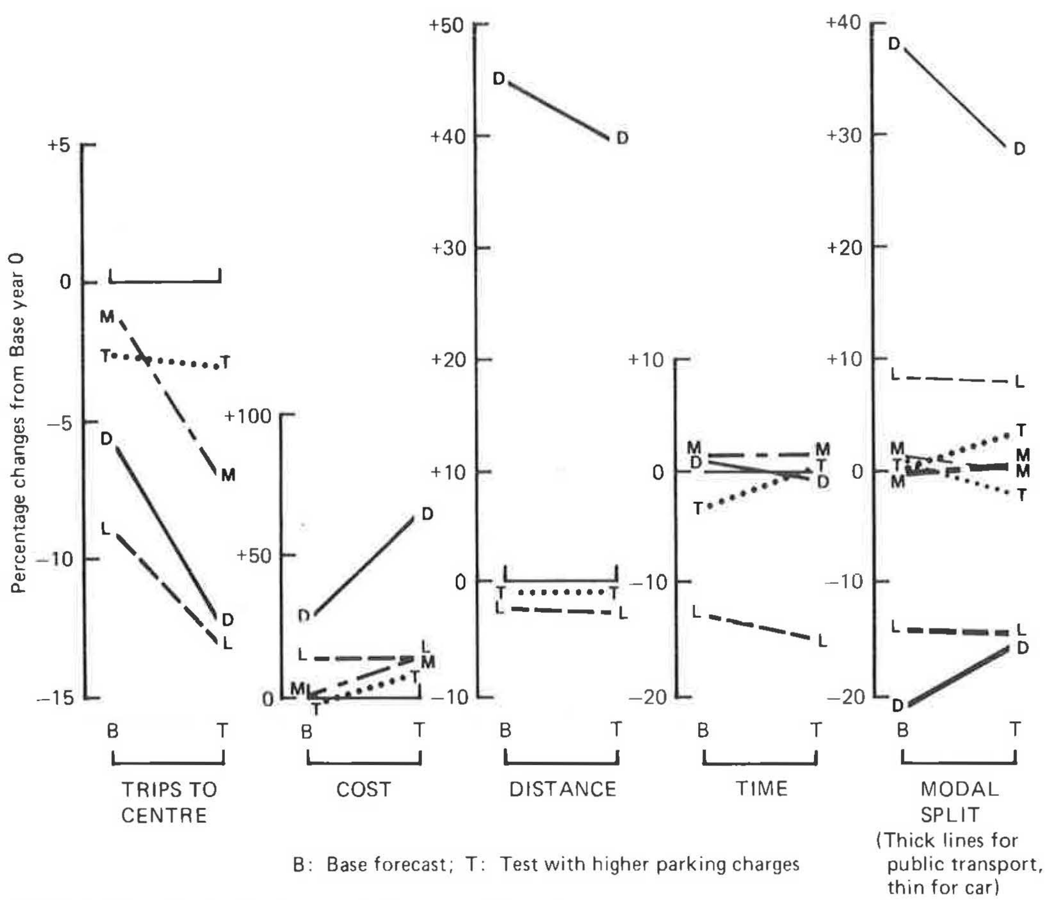

FIGURE 2 Effect of higher central area parking charges on proportion of travel to center, average journey cost, distance, time, and modal split.

more, but largely because this model predicts a 20 percent reduction in car ownership. Some reduction is plausible, but this appears large, and, in general, the expenditure budget basis of DORTMUND's car ownership model appears to make it oversensitive to changes in travel cost.

Figure 3 shows that retail employment is more responsive than the other categories, as was noted in the first example. In LILT, MEP, and TOPAZ at least, it appears that the imposition of high parking charges in an attempt to restrain car use in the area may have seriously unwelcome side effects on commercial activity in the city center. This test provides a good example of the importance of using a fully interactive land use–transport model to examine a transport policy; the land use aspects are probably more important to the city authorities than are the direct transport effects. The test also illustrates the type of divergence between the behavior of the models that on occasion has led the modelers to conclude that a particular mechanism might usefully be modified for future versions of the model; for example, for some applications modification of DORTMUND's car ownership model would be desirable.

Example 3: Bringing Jobs Closer to the Workers

It is often argued that if employment were distributed in closer relation to the population there would be less need to travel, which would save travel time, cost, and energy. This test looked at this situation by distributing all nonservice employment throughout the urban area in proportion to population: in most models, this was interpreted as requiring the same percentages of total nonservice employment and total population in each zone. Over the 20-year prediction there was a tendency for this redistribution of employment to gradually move back toward the distribution seen in the base forecast, except where constraints were placed on relocation to maintain the prescribed balance. This forced redistribution of nonservice employment had relatively little effect on the eventual distribution of either population or service employment, and indeed little is to be expected because with nonservice employment so dispersed there is little the population can do to improve its accessibility to employment by relocating. This is not to say that this distribution of employment necessarily maximizes accessibility: in some cases a more centralized distribution might be better, but once the dispersed location is achieved the pattern of accessibility provides little incentive for any further redistribution.

TABLE 3 EFFECTS OF BRINGING EMPLOYMENT CLOSER TO THE POPULATION ON CAR OWNERSHIP AND JOURNEY CHARACTERISTICS

	Percent Change Relative to Base Year 20 According to Model			
	C	D	L	M
Car ownership		−0.8	−0.3	
Average journey characteristics				
Average time per work trip	0.2	−5.2	3.7	−1.5[a]
Average distance per work trip		−1.1	0.4	
Average money cost per work trip	0.6	−3.4	−1.1	−0.8[a]
Total travel time per head	0.7	−2.3	1.4	−0.8
Average energy use per head		−0.6	−0.7	

[a]All trip purposes.

The main aspects of interest here lie in the response of the travel pattern, however. Naturally, general decentralization produces a decline in the proportion of trips made to the central area, but changes in overall modal split are relatively small: DORTMUND shows the net transfer from public transport to car that might be expected from the more dispersed travel pattern, but in LILT and MEP there is very little change at all. Table 3 gives a summary of the changes in the other travel parameters where they are available from the models (OSAKA also completed the test but provides no explicit representation of the travel pattern). Both LILT and DORTMUND predict a small reduction in car ownership because of a transfer to walking, and most of the models predict a reduction in travel time and money cost. DORTMUND predicts a reduction in

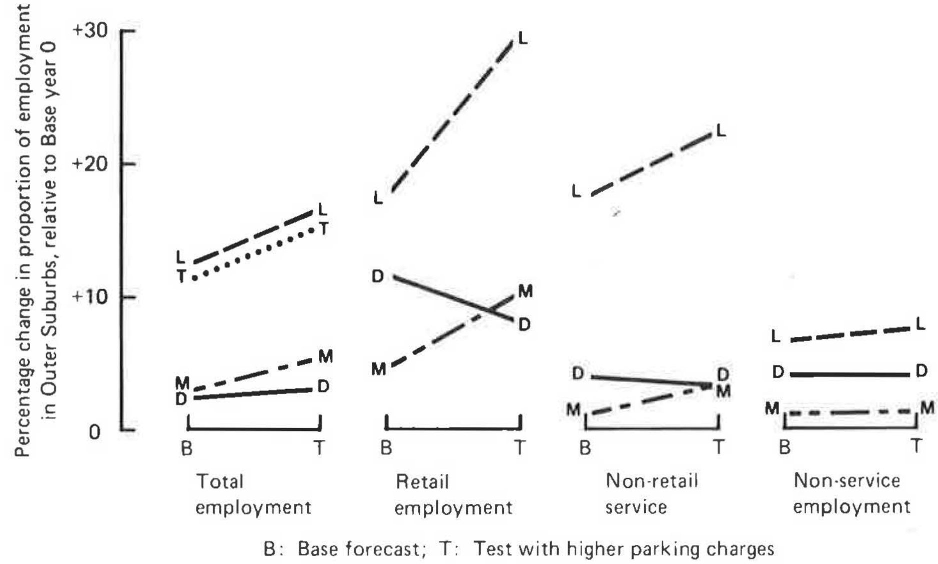

FIGURE 3 Effect of higher central area parking charges on distribution of employment.

average distance to work, but LILT shows a slight increase. DORTMUND and LILT both predict a reduction in energy use. Thus bringing employment closer to the workers has achieved some saving in transport resources, but the models suggest that this radical relocation of employment would in practice have a remarkably small effect on overall travel costs, time, or energy. It appears that people would still travel as much as ever to maximize their choice of employment.

CONCLUSION

The ISGLUTI study was acknowledged from its inception to be a rather ambitious project. Comparison of so many complex models is a difficult and time-consuming business. For the researchers involved, the process has been educational—not the least of the benefits has been that the modelers themselves have learned more about their own models than they would have in the absence of the study. What appeared to be an overwhelming jumble of data has been tamed, and convincing and consistent conclusions are being extracted. The report of the first phase of the study should be published in the second half of 1987.

In this paper it has been possible to provide only the briefest overview of the models and the bare bones of three of the tests to illustrate the procedure. On the basis of individual tests it is not generally possible to say whether differences in response between the models are due to differences between the cities on which they are based or to different mechanisms within the models themselves. This difficulty persists throughout the program of tests, but by viewing all of the results together it becomes possible to identify the characteristic behavior of individual models, to judge to some degree their plausibility, and to identify certain aspects that require improvement.

In this exercise, these models are being exposed to a more searching scrutiny than most of the models in current use have ever experienced. Comparison on this scale is probably unique. Certainly, there are areas in which the behavior of some of the models appears unsatisfactory. There have been other examples in which, on closer inspection, an apparent implausibility has been seen to be entirely realistic and has contradicted the initial intuitive expectation. These occasions are, of course, especially valuable because these models are not to be used unthinkingly but to challenge and, if necessary, modify the user's view of the world. For the most part, the models have proved plausible across a wide range of conditions.

Many questions remain unanswered, of course. The compounding of city differences with model differences confuses some of the analysis of the first phase of the study, but the second phase, with its transfer of models between the data bases, should go a long way toward separating the effects and identifying more reliably areas of agreement and disagreement among the models. In addition to providing information about the relative merits of the modeling, the study is also gathering many pointers and much food for thought about the effects of a wide range of land use and transport policies. In the end, it is likely that the study will achieve general agreement about the directions of these effects, but questions will remain about their strengths. To solve those reliably, suitable opportunities and adequate data must be awaited to compare the model predictions with reality across some major, and well-monitored, transport investment.

ACKNOWLEDGMENTS

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REFERENCES

1. I. S. Lowry. *A Model of Metropolis.* Rand Corporation, Santa Monica, Calif., 1964.
2. D. B. Lee. Requiem for Large-Scale Models. *Journal of American Institute of Planners,* Vol. 39, 1973, pp. 163–178.
3. J. R. Pack. Urban Models: Diffusion and Policy Application. *Regional Science Research Institute Monograph Series,* No. 7, Philadelphia, Pa., 1978.
4. R. A. Sayer. Understanding Urban Models Versus Understanding Cities. *Environment and Planning A,* Vol. 11, 1979, pp. 853–862.
5. H. Floor. The Use of Spatial Interaction Models in Planning: Some Examples. In *Zur Methodologie und Methodik der Regionalforschung* (Bahrenberg and Deiters, eds), University of Osnabrück, Federal Republic of Germany, 1984.
6. H. Nakamura, Y. Hayashi, and K. Miyamoto. Land Use–Transportation Analysis System for a Metropolitan Area. In *Transportation Research Record 931,* TRB, National Research Council, Washington, D.C., 1983, pp. 11–20.
7. M. Wegener. Modelling Urban Decline: A Multilevel Economic-Demographic Model for the Dortmund Region. *International Regional Science Review,* Vol. 7, 1982, pp. 217–241.
8. S. H. Putman. *Integrated Urban Models: Policy Analysis of Transportation and Land Use.* Pion, London, England, 1983.
9. R. L. Mackett. *The Leeds Integrated Land Use-Transport Model (LILT).* TRRL Report SR805. Transportation and Road Research Laboratory, Department of Transport, Crowthorne, Berkshire, England, 1983.
10. P. Geraldes, M. H. Echenique and I. N. Williams. A Spatial Economic Model for Bilbao. *Proc., Stream F, PTRC Summer Annual Meeting,* PTRC, London, England, 1978, pp. 75–94.
11. K. Amano, T. Toda, and H. Abe. The Hierarchical Urban Model and Its Application to the Osaka Metropolitan Area. Presented at the European Conference of Regional Science Associations, Poitiers, France, Aug. 1983.
12. L. Lundqvist and L.-G. Mattsson. Transportation Systems and Residential Location. *European Journal of Operational Research,* Vol. 12, 1983.
13. J. F. Brotchie, J. W. Dickey, and R. Sharpe. *TOPAZ—General Planning Technique and Its Application at the Regional, Urban and Facility Planning Levels.* Springer-Verlag, Berlin, Federal Republic of Germany, 1980.

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Mathematical Programming Formulations of Transportation and Land Use Models: Practical Implications of Recent Research

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The next generation of transportation, location, and land use models will most probably emerge from mathematical programming formulations. Presented are simple numerical examples of trip assignment and population location, both described as optimization problems, in mathematical programming formulations. A trip assignment model with constant link costs is described first, and then the same model is modified to show the consequences of a flow-dependent link cost formulation. In similar fashion, a linear model of least cost population location is transformed into a nonlinear model that incorporates dispersion of location due to differences in locators' preferences or perceptions. It is then shown how the trip assignment model and the location model can be combined into a single nonlinear programming formulation that solves both problems simultaneously. In the final section of the paper, the theoretical advantages and practical disadvantages of this approach are briefly enumerated. This is followed by suggestions about the likely resolution of practical problems to allow use of these techniques in applied planning situations.

There has been considerable refinement of practical methods of forecasting urban location and transportation patterns during the past 10 to 15 years. Although there is continuing discussion and development, and even the best of forecasts are far from perfect, there appears to be a greater consensus on what methods are clearly outmoded and in what directions future efforts should move. This author's views on general progress in the field have already been published *(1)*. Among the most sophisticated practical methods of transportation and land use forecasting are the extended spatial interaction models, especially when they are included in comprehensive integrated model systems [see paper by Bly and Webster in this Record and Putman *(2)*].

In addition to these practical developments there have also been important theoretical developments. On the transportation side these include the development of discrete choice models, especially for travel demand and mode choice *(3)*, and the development of mathematical programming formulations of the traffic assignment problem *(4)*. On the location side the development of utility theory as a basis for location models *(5)* and the general discussion of mathematical programming models as alternate or underlying structures for spatial interaction models *(6)* were major developments. Some of these developments are important principally because they provide an improved underpinning of existing practical methods; some have shown the existence of clear errors in prior practice; and others may offer substantial improvements for future applications.

Past experience suggests that there is a lag of 10 years, sometimes more, between the initial development and subsequent practical application of new techniques in transportation and land use forecasting. Thus, although there have been some attempted applications of these methods *(7, 8)*, they are far from being the accepted norm. The purpose of this paper is to present some illustrations of the mathematical programming formulations along with some simple numerical examples. The intent is to show some of the benefits, both practical and theoretical, of these formulations and to provide the practical planner with an introduction to this promising new area.

NETWORKS AND TRIP ASSIGNMENT

In the discussion that follows, extensive use will be made of the data describing Archerville, a simple five-zone numerical example. Table 1 give the land use and socioeconomic data for Archerville. Figure 1 shows the Archerville highway system.

Shortest Path Problem

A frequently encountered problem in transportation and location analyses is that of finding the shortest path from one node to another over the links of a network. This is a problem that can be considered as a linear programming problem. The equation form is

$$\text{Min: } Z = \sum_i \sum_j c_{ij} X_{ij} \tag{1}$$

subject to

$$\sum_j X_{ki} - \sum_k X_{ki} = \begin{cases} 1 \text{ if } i = \text{origin} \\ -1 \text{ if } i = \text{destination} \\ 0 \text{ otherwise} \end{cases} \tag{2}$$

$$X_{ij} \geq 0 \quad (\forall\, i, j) \tag{3}$$

where c_{ij} is cost of traversing link i, j and X_{ij} is flow (trips) on link i, j.

The objective function is straightforward: simply to minimize the sum of the link cost times the trips incurring that cost. The principal constraint equations (Equations 2) are a set of flow-balance relationships that ensure that the flows, at each

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TABLE 1 ARCHERVILLE—LAND USE AND SOCIOECONOMIC DATA

	Land Use Data					Socioeconomic Data					
Zone	Residential	Commercial	Industrial	Vacant	Total	Commercial Employment	Industrial Employment	Total Employment	LI Households	HI Households	Total Population
1	2.5	1.0	1.0	0.5	5.0	150	150	300	200	100	860
2	3.0	1.0	1.5	0.7	6.2	200	150	350	300	50	1,050
3	1.0	2.0	3.0	0.8	6.8	100	400	500	150	50	585
4	2.5	1.0	0.0	4.5	8.0	200	0	200	100	300	550
5	1.5	0.5	0.0	6.6	8.6	100	0	100	50	150	515
Total						750	700	1,450	800	650	3,560

Employee-Household Cross Tabulation

	LI	HI	Total
Commercial	400	350	750
Industrial	400	300	700
	800	650	1,450

Employee-Household Conversion Matrix

	LI	HI	Total
Commercial	.533	.467	1.00
Industrial	.571	.429	1.00

NOTE: LI = low-income and HI = high-income.

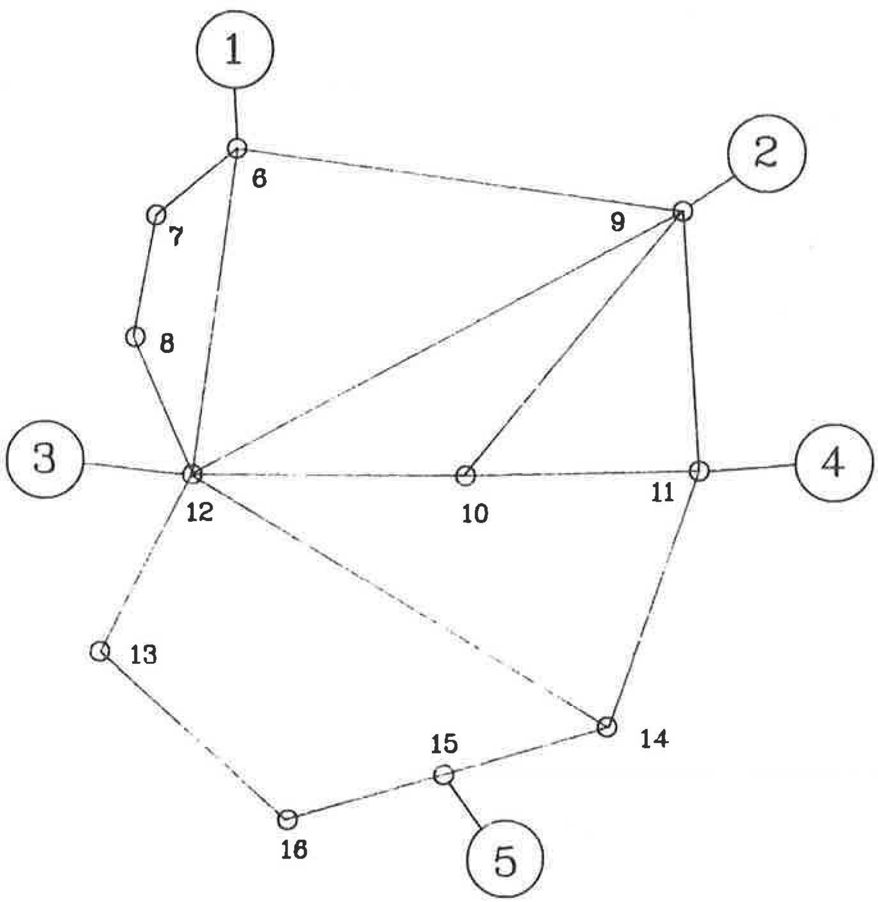

FIGURE 1 Archerville highway system.

network node, balance. Thus for each node the total flow of trips into the node minus the total flow of trips out of the node must equal the net trips supplied (or demanded) at the node. The last constraint equation (Equation 3) is simply the non-negativity requirements that prohibit negative flows. It can readily be seen that writing the shortest path problem in this form yields a rather good sized problem. In the objective function the number of terms equals the number of links in the network. There must be a constraint equation (Equation 2) for each network node and a constraint equation (Equation 3) for each network link.

For practical applications there are many fast algorithms for solving this problem. However, it is worth noting here that, because this is just a simple linear program, it can be solved by the well-known simplex method. If it were done that way, it would be necessary to solve the problem once for each origin-destination path that was wanted. Further note that this problem only addresses the situation for fixed link costs and flow volumes, which must, of course, be known in advance of any attempt to solve for the minimum path or paths.

Minimum-Cost Flow Problem

Another type of linear programming problem is that known as the minimum-cost flow problem. The Archerville data may be used as an example. Assume that there are a known number of households of each income group in each zone and a known number of employees of each type working in each zone. Implicitly there is a zone-to-zone matrix of home-to-work trips that can be estimated by standard techniques. Suppose now that the location of households in Table 1 and the location of industrial employment in the same table are taken as given. By first assuming that there will be one employee per household and then applying the Employee-Household Conversion Matrix given in Table 1, the number of industrial employees residing in each zone may be calculated. These were 146, 173, 98, 188, and 95, respectively. Note that the number of industrial employees working in each zone is 150, 150, 400, 0, and 0, respectively.

It is possible to consider the proposal that each employee is to choose a place of work such that the total travel cost for all employees is minimized. If network link capacities, and the consequent congestion, are ignored for this illustration, this problem may be stated as a linear program

$$\text{Min: } Z = \sum_i \sum_j c_{ij} X_{ij} \tag{4}$$

subject to

$$\sum_j X_{ij} - \sum_k X_{ki} = \begin{cases} O_i \text{ if } i = \text{origin} \\ -D_i \text{ if } i = \text{destination} \\ 0 \text{ otherwise} \end{cases} \tag{5}$$

$$X_{ij} \geq 0 \quad (\forall\, i, j) \tag{6}$$

where O_i is net trips leaving node i and D_i is net trips arriving at node i.

Equations 4, 5, and 6 are the general minimum-cost flow problem. If there were specified link capacities (V_{ij}) for each link, which could not be exceeded, then another set of constraints would be substituted for Equation 6. This new set of constraints would be of the form

$$V_{ij} \geq X_{ij} \geq 0 \quad (\forall\, i, j) \tag{7}$$

Note that the objective function here is the same as that for the shortest path problem given in Equation 1. The constraints, Equations 5, are a set of flow-balance relationships similar to those of Equations 2.

Because the intrazonal travel costs are 1.0 for each zone, clearly the first consideration is that all employees residing in any zone first be assigned to jobs in that zone. Given the Archerville data, Zone 1 requires 4 workers and Zone 3 requires 302. Zones 2, 4, and 5 have 23, 188, and 95 surplus workers, respectively. The link flows produced by the simplex algorithm to solve this problem are shown in Figure 2. Note that if it were desired that some of the network links have a maximum allowable flow, then some constraints of the form of Equation 7 would have to be added.

Nonlinear Minimum-Cost Flow Problem

The minimum-cost flow problem described here can be reconsidered as a nonlinear programming formulation. In the previous formulation the linear objective function, Equation 4, was simply the sum of the trips (flows) on each network link times the travel cost of the link. The link costs were fixed, remaining constant regardless of link flows (though it was shown how the link flows could themselves be restricted by use of additional constraint equations). Suppose the more realistic view was taken that link costs depend on link flows. For the sake of illustration consider the following function, where link cost varies with link flow

$$C_{ij} = C^o_{ij}\,(1.0 + \delta X^2_{ij}) \tag{8}$$

where

C_{ij} = "congested" or flow-related link travel cost,
C^o_{ij} = free-flow link travel cost,
X_{ij} = link flow volume (trips), and
δ = a parameter.

With this function the link travel cost is equal to the free-flow cost when the link flow volume is zero. As link flow volume increases, link travel cost increases too.

In the linear version of this problem the solution involved only the finding of the minimum paths and the subsequent routing of trips along those paths. If there were specific link flow volume constraints, then the excess trips would be rerouted to the second shortest path. When link flows determine link costs the essential nature of the problem changes. The solution becomes a matter of adjusting volumes, observing the resulting costs, and then adjusting the volumes again. Thus, in a very real sense, even for the small problem size of the Archerville data the complexity of the problem begins to defy

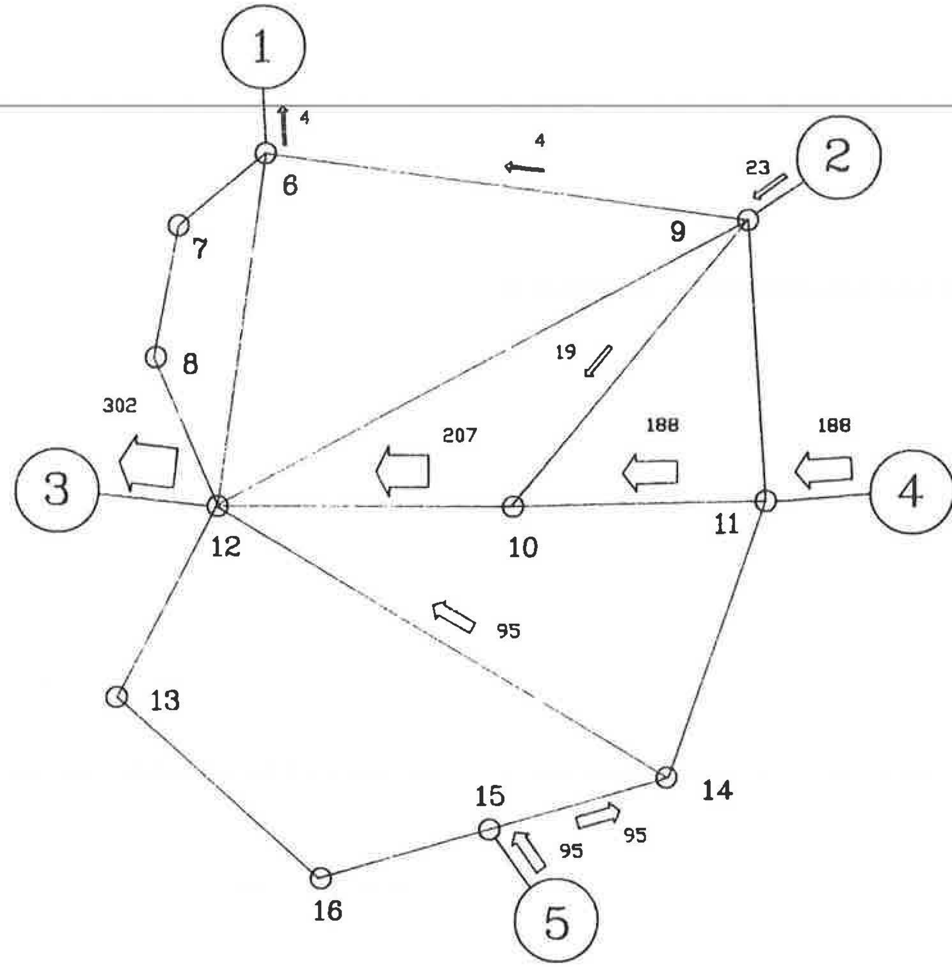

FIGURE 2 Archerville trip flows resulting from minimum-cost flow assignment algorithm with constant link costs.

solution by inspection. The introduction of simultaneity or nonlinearity, or both, to a problem often transforms the problem into one that lies beyond intuitive solution.

Incorporating Equation 8 into the original objective function of Equation 4 yields

$$\text{Min: } Z = \sum_i \sum_j \left[C_{ij}^o \, (1.0 + \delta X_{ij}^2) \, X_{ij}\right] \tag{9}$$

and thus the objective function becomes a cubic equation. The same linear constraints as before (Equations 5, the flow-balance relationships) still hold true, as do the nonnegativity constraints of Equation 6. This new set of equations is a nonlinear programming (NLP) problem with a nonlinear objective function and linear constraints.

It was necessary to set a value for the parameter δ. A value of 0.0002 was selected so that link flow volumes on the order of 100 trips would result in a tripling of link cost. At this scale, link costs increase significantly, but not astronomically, with link flows on the order of those observed in the linear form of the problem described previously. The flows on the network that result from this new nonlinear problem are shown in Figure 3, and the link volumes, free-flow link costs, and congested link costs are given in Table 2 (only those links that have flows are included). The results hold no great surprises but do show a clear response to the reformulation of the problem so that link costs are a function of link flows.

It is interesting to compare the results shown in Figure 3 from the NLP solution with those in Figure 2 from the linear programming (LP) solution. The NLP solution, due to the effects of congestion on link travel costs, shows much greater utilization of network links. For the LP solution only 11 links were used whereas for the NLP solution 20 were used. As a result, the trips on links $X_{11,10}$ and $X_{10,12}$, which were 188 in the LP solution, are only 112 in the NLP solution.

These examples only hint at the substantial additional work that has been done with user equilibrium and stochastic user equilibrium formulations of the traffic assignment problem as a mathematical program. Yet, they do give a clear way of seeing the assignment problem, as well as networks in general, expressed in equation form. This will be particularly helpful in analyzing ways of linking transportation and location models. This insight also provides a much easier way of comprehending the problems of traffic assignment than did the "black-box" approach of traditional all-or-nothing assignment procedures. In the next section of this paper simple examples will be presented of location models presented as mathematical programs.

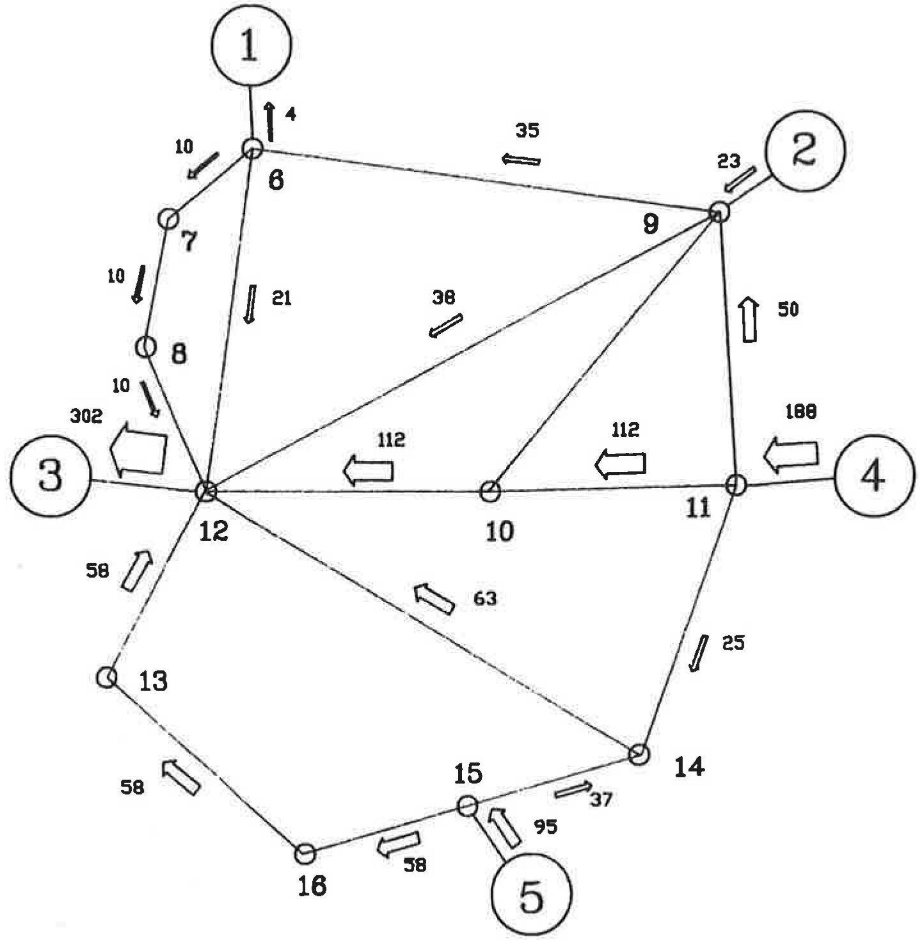

FIGURE 3 Archerville trip flows resulting from minimum-cost flow assignment algorithm with variable link costs.

TECHNIQUE FOR THE OPTIMAL PLACEMENT OF ACTIVITY IN ZONES: TOPAZ

TOPAZ is a mathematical programming technique that was originally proposed in the late 1960s and early 1970s *(9, 10)*. The most complete discussion of the applications of the model is to be found in the book by Brotchie et al. *(11)*. The model was originally proposed as a method for determining least cost allocations of activities to zones. Perhaps the most recently published work on TOPAZ is by Sharpe et al. *(12)* from which the formulation used here is adapted.

To begin, the model was abbreviated to a form for residence location only. Further, it was assumed, as is customary in these examples, that there is one employee per household and thus one work trip per household. The Archerville data show 0.55 low-income households per 1.0 employee and 0.45 high-income households per 1.0 employee. Thus the new, simplified, problem formulation becomes

$$\text{Min: } Z = \sum_i \sum_j \sum_l T_{ijl}\, c_{ijl} + \sum_i \sum_j b_{ij}\, X_{ij} \qquad (10)$$

subject to

$$\sum_l T_{ijl} - s_i X_{ij} = 0 \qquad (11)$$

$$\sum_j T_{ijl} - r_i X_l = 0 \qquad (12)$$

$$\sum_j X_{ij} = A_i \qquad (13)$$

$$\sum_i X_{ij} \leq Z_j \qquad (14)$$

$$T_{ijl} \geq 0, X_{ij} \geq 0 \qquad (15, 16)$$

where

A_i = regional total of activity i,
b_{ij} = unit cost less benefit of locating activity i in zone j,
c_{ijl} = unit cost less benefit of interaction for activity i between zone j and zone l,
s_i = level of interaction (trips generated) per unit of activity i,
r_i = trips attracted by employment per unit of activity i,
T_{ijl} = level of interaction (trips) of activity i between zone j and zone l,
X_{ij} = amount of activity i to be allocated to zone j, and
Z_j = capacity of zone j.

Note that the second term in the objective function is simply a minimum-cost location term. The first term is the linear

TABLE 2 ARCHERVILLE—COMPARISON OF FREE-FLOW AND CONGESTED LINK COSTS FOR NONLINEAR OBJECTIVE FUNCTION

Link	Volume	Free-Flow Cost	Congested Cost
$X_{2,9}$	23	1.00	1.11
$X_{4,11}$	188	1.00	8.07
$X_{5,15}$	95	1.00	2.81
$X_{6,1}$	4	1.00	1.00
$X_{6,7}$	10	2.00	2.04
$X_{6,12}$	21	5.00	5.44
$X_{7,8}$	10	2.00	2.04
$X_{8,12}$	10	2.00	2.04
$X_{9,6}$	35	4.00	4.96
$X_{9,12}$	38	7.00	9.07
$X_{10,12}$	112	2.00	7.06
$X_{11,9}$	50	5.00	7.52
$X_{11,10}$	112	1.00	3.53
$X_{11,14}$	25	4.00	4.52
$X_{12,3}$	302	1.00	19.24
$X_{13,12}$	58	2.00	3.33
$X_{14,12}$	63	6.00	10.74
$X_{15,14}$	37	2.00	2.56
$X_{15,16}$	58	2.00	3.33
$X_{16,13}$	58	4.00	6.65

"transportation" problem. Taking the location problem first, it is clear that developing the necessary "data" raises some difficult issues. The net benefits (b_{ij}) are supposed to be the net of the costs and benefits of locating a unit of activity type i in zone j. In many TOPAZ applications the virtual impossibility of measuring benefits resulted in the b_{ij} being simply a cost of location, to be minimized. For the Archerville example several possibilities existed. The easiest way was simply to create an average annualized house cost variable, realizing that then the model would attempt to locate all households in the zone with the lowest house cost. All that prevents this location are the constraints on the amount of activity that can be accommodated in each zone.

Raising the issue of zonal constraints raises, in turn, the issue of converting activity types into land consumed. Here again, there were several possible ways to proceed: (a) regional land consumption rates by activity type, (b) zonal land consumption rates by activity type, or (c) exogenously developed housing stock estimates. For this illustration of the model a set of regional land consumption rates was assumed, and their values were set so as to allow all households to be accommodated by existing residential land in the region. The rates were 0.00525 land units per low-income (LI) household and 0.00646 land units per high-income (HI) household. The cost of location by zone was taken to be the average annualized house cost by zone, which was set to $7,800, $7,200, $7,600, $6,800, and $9,668, respectively, for the five zones.

Next the transportation, or interaction, cost term in the objective function (Equation 10) was examined. This required the specification of data for the trip end constraints (Equations 11 and 12) as well. As mentioned previously, it was assumed that there was only one employee per household and that there were 0.55 LI and 0.45 HI households per employee. Recalling that, in this example, only home-to-work trips are being dealt with and there is only one employment type, then both s_i will equal one, so that the constraint equations (Equation 11) will be

$$\sum_l T_{ijl} - X_{ij} = 0$$

or, in words, the sum over all possible destination zones l of all trips of type i leaving (i.e., produced in) zone j must equal the trips of type i generated in zone j. In this example the trips of type i (i.e., household type i) generated in zone j equal the number of households of type i living in zone j.

Following the same reasoning, the r_i will be equal to the household-type-per-employee ratios, so that the constraint equation (Equation 12) will be as given earlier, with $r_i = 0.55$, $R_2 = 0.45$, and X_l = total employment in zone l. Then, in words, the sum over all possible origin zones j of all trips of type i terminating in zone l must equal the total households of type i attracted to employment in zone l. The total households of type i attracted to employment in l is simply the conversion rate times the employment.

An extensive series of test runs was done with this model with varying weightings multiplied times one or another of the two components of the objective function. At the extremes, a location-cost-only solution and a transportation-cost-only solution were found. The minimum transport cost solution gave somewhat more dispersion of households to zones than did the minimum location cost solution. This was due in large part to the exogenously determined location of employment. Were employment to be less dispersed, then, subject to the land use contraints, residential location would be less dispersed as well.

Another matter that will have interesting consequences for the next set of tests, in which both location and interaction costs are used along with a dispersion term to determine residential location, was that even though the location cost component was almost four times larger than the transport cost component, the transport cost portion of the objective function completely dominated the model solution. In several more test runs the weighting of the location cost term in the objective function was varied from 0.01 to 2.00.

Over the range from 0.045 to 1.00 the location cost multiplier resulted in a more or less gradual shift from the transport-cost-only solution toward the location-cost-only solution. From a value of slightly less than 1.0 to a value of 1.1852 the multiplier causes no change in the model solution. At a value of 1.1855 the multiplier results in a model solution identical to that of the location-cost-only solution. Thus at some critical point where the multiplier of the location cost term in the objective function is between 1.1852 and 1.1855, there is a sudden shift in the model solution from an apparently stable intermediate solution to the location-cost-only solution. Although it is presented as an aside here, clearly the matter of model sensitivity and solution stability is an area for future research. In any case, for a midrange weighting of 0.70, the results of the TOPAZ model solution were as given in Table 3.

Numerical Example Incorporating Dispersion

The location patterns produced by the linear programming version of this model, particularly when examined at the zone-to-zone trip level, are rather lumpy. The addition of a nonlinear dispersion term to the objective function can make a noticeable difference. This is achieved by substituting a constrained gravity model for the linear "transportation" model portion of the objective function.

TABLE 3 ARCHERVILLE—LOCATION OF HOUSEHOLDS BASED ON LOCATION COST PLUS TRANSPORT COST COMPONENTS OF MODEL (λ_2 = 0.70)

	Households			Households, Showing Place of Work	
Zone	LI	HI	Total	LI	HI
1	0	294	294	0	1-135 3-69 4-45 5-45
2	359	173	532	1-166 2-193	2-157 4-16
3	0	155	155	0	3-155
4	441	28	469	3-276 4-110 5-55	4-28
5	0	0	0	0	0

NOTE: λ_2 = location cost multiplier in objective function.

The standard doubly (or fully) constrained spatial interaction model has the form

$$T_{jl} = A_j B_l O_j D_l \exp(-\beta c_{jl}) \quad (17)$$

where

T_{jl} = number of trips between zone j and zone l,
O_j = trips generated in (originating from) zone j,
D_l = trips attracted to (terminating in) zone l,
c_{ij} = zone-to-zone travel cost, and
β = a parameter;

and where

$$A_j = \left[\sum_l B_l D_l \exp(\beta c_{jl}) \right]^{-1} \quad (18)$$

$$B_l = \left[\sum_j A_j O_j \exp(-\beta c_{jl}) \right]^{-1} \quad (19)$$

It has been shown by Murchland *(13)* and Wilson *(14)* that this model can be derived from an equivalent optimization problem. The form of that problem is

$$\text{Max: } S = -\sum_j \sum_l T_{jl} \ln T_{jl} \quad (20)$$

subject to

$$\sum_l T_{jl} = O_j \quad (21)$$

$$\sum_j T_{jl} = D_l \quad (22)$$

$$\sum_j \sum_l c_{jl} T_{jl} = C \quad (23)$$

where the only new value is C, taken to represent the total system travel cost.

There is a relationship between β in Equations 17–19 and C in Equation 23. The β in the spatial interaction model produces a dispersion of trips away from the optimum or minimum-cost solution. What human behavior might account for this dispersion is unspecified but presumably includes such factors as variables not in the model, as well as variations in individual perceptions of costs and differences in individual utility functions.

To introduce the spatial interaction model into TOPAZ in lieu of the minimum-cost "transportation" model requires that the model of Equations 20–23 be substituted for the transport cost term in the TOPAZ objective function. Following algebraic manipulations, this yields (after changing signs to allow minimization)

$$\text{Min: } S = \frac{1}{\beta} \sum_i \sum_j \sum_l T_{ijl} \ln T_{ijl} + \sum_i \sum_j \sum_l T_{ijl} c_{ijl} + \sum_i \sum_j b_{ij} X_{ij} \quad (24)$$

subject to

$$\sum_l T_{ijl} - s_i X_{ij} = 0 \quad (25)$$

$$\sum_j T_{ijl} - r_i X_l = 0 \quad (26)$$

$$\sum_j X_{ij} = A_i \quad (27)$$

$$\sum_i X_{ij} \le Z_j \quad (28)$$

$$T_{ijl} \ge 0, \; X_{ij} \ge 0 \quad (29, 30)$$

The Archerville data were again used for tests of the model, which now required a numerical value of β. This, however, raises an interesting question, which relates directly to the previously described experiments with weightings or multipliers of the terms in the objective function. To simplify the coming discussion it will be convenient to think of the objective function, Equation 24, as having three components:

$$\text{Min: } Z = \lambda_3 U_3 + \lambda_1 U_1 + \lambda_2 U_2 \quad (31)$$

where λ_1, λ_2, and λ_3 are arbitrary weights, and where U_1 is the transport cost term, U_2 is the location cost term, and U_3 is the entropy term. The no-dispersion solution given in Table 3 was for λ_1 equals one, λ_2 equals 0.70, and λ_3 equals zero.

The value of λ_3 as discussed here is the inverse of the β of Equation 17 and thus will directly affect the extent to which location is dispersed from the no-dispersion case where $\lambda_3 = 0$ and thus $\beta = \infty$. With a λ_3 of 20 and thus $\beta = 0.05$, the dispersion shows quite clearly in the results given in Table 4. A further increase in λ_3, to 30, giving $\beta = 0.033$, yields even greater dispersion. Numerous tests were run with different combinations of values for λ_1, λ_2, and λ_3. In all cases increasing values of λ_3 produced increased dispersion of household location. The most dispersion was achieved with values of λ_1 equal to one, λ_2 in the vicinity of 0.3, and λ_3 equal to 30 or more. The conclusion here is simple, the addition of a dispersion term to the objective function of a mathematical programming model of residence location results in a more even distribution of residents to zones and is probably a more realistic representation of actual human behavior.

TABLE 4 ARCHERVILLE—LOCATION OF HOUSEHOLDS BASED ON LOCATION COST PLUS TRANSPORT COST COMPONENTS OF MODEL ($\lambda_2 = 0.70$), INCORPORATING DISPERSION, WITH $\beta = 0.05$

	Households			Households, Showing Place of Work	
Zone	LI	HI	Total	LI	HI
1	45	258	302	1-42 3-3	1-128 2-21 3-84 4-14 5-11
2	319	205	524	1-105 2-181 3-25 4-4 5-4	1-6 2-135 3-17 4-32 5-15
3	20	138	158	1-1 3-19	3-117 4-12 5-9
4	416	49	465	1-18 2-11 3-230	3-6 4-33 5-10 4-106 5-51
5	0	0	0	0	0

NOTE: λ_2 = location cost multiplier in objective function.

COMBINED ACTIVITY LOCATION AND TRIP ASSIGNMENT MODEL

Having shown in the preceding two sections of this paper how both a traffic assignment model and an activity location model could be formulated as mathematical programming problems, it is now possible to consider linking them together into a single model to solve both problems simultaneously.

First, note that the original transport cost term in the location model objective function is simply the sum of all trips between origins j and l, times the cost of those trips. It is reasonable to assume that, regardless of whether a congested or uncongested network is being used in the model, the costs used will be those of the minimum paths through the network. In the location model the zone-to-zone costs used are the exogenously determined minimum costs given as input to the calculations. The minimum-cost flow problem determines the set of minimum cost paths through the network. Given that these minimum paths are the same, the flow cost produced by the minimum-cost flow problem solution should be identical to the transport cost term in the location model objective function.

In the nonlinear version of the location model the entropy term of the cost function takes care of keeping the zone to zone trips in the objective function, thus the transport cost term can be replaced by the objective function from the minimum-cost flow problem. It will, of course, be necessary to add the flow balance constraints in order to describe the network, and to set them equal to what is now a variable set of trip origins and destinations. These are now variable because the activity locations, and thus the trip matrix, are to be determined as part of the model solution. Thus the combined model has the following form:

$$\text{Min: } S = \sum_i \sum_m \sum_n d_{mn} F_{imn} + \frac{1}{\beta} \sum_i \sum_j \sum_l T_{ijl} \ln T_{ijl} + \sum_i \sum_j b_{ij} X_{ij} \quad (32)$$

subject to

$$\sum_i \sum_n F_{imn} - \sum_i \sum_n F_{inm} = \begin{cases} \sum_i (s_i X_{im} - r_i E_m) & m \leq J \\ 0 & m > J \end{cases} \quad (33)$$

$$\sum_l T_{ijl} - s_i X_{ij} = 0 \quad (34)$$

$$\sum_j T_{ijl} - r_i E_l = 0 \quad (35)$$

$$\sum_j X_{ij} = A_i \quad (36)$$

$$\sum_i X_{ij} \leq Z_j \quad (37)$$

$$T_{ijl} \geq 0,\ X_{ij} \geq 0,\ d_{mn} > 0 \quad (38, 39, 40)$$

where the variable names d and F (link cost and link flow) are substituted for the c and X used in the minimum-cost flow problem equations. J is the number of zones (load nodes). In addition employment in zone l is represented by E_l in Equation 35 to avoid confusion.

The objective function now has three terms, minimum-cost flows, entropy or trip dispersion, and minimum-cost location. A new set of constraints (Equations 33) is added to the previous set of location model constraints to incorporate the flow-balance portion of the minimum-cost flow problem. This being done it is possible to solve the combined problem for both link flows and household location. Now it is possible to include congestion in this problem too. The first term in the objective function (Equation 32) is modified as per Equation 9 to make link cost a function of link volume (flow). The remainder of the objective function and all of the constraints are unchanged.

CONCLUSIONS

The work described in this paper is only a brief introduction to the topic, yet certain conclusions can now be clearly drawn. The first of these is that numerous model tests using the kinds of models described here indicate that linear mathematical programming models of location are inherently unrealistic. The least-cost zone will get all possible locators even if the next-to-least-cost zone is only marginally more expensive. The objective function component weighting problem implies that an arbitrary difference in units of measurement (e.g., between hundreds of dollars or thousands of dollars for annualized rent) can result in one component of a model solution's being dominant over another.

To a rather considerable degree the constraint equations of a linear programming model can ameliorate some of these difficulties. This is, however, a mixed blessing. That they can ameliorate some of the difficulties also points up the rather considerable extent to which they determine the model solution. The constraints (e.g., available residential land per zone) must be exogenously determined, yet their determination, in and of itself, implies a difficult forecasting problem. The availability of data for constraints during the development of a mathematical programming location model can give a false sense of confidence in the model's predictive power if the problems of forecasting the constraints are not taken into account.

Another major issue is that of obtaining the necessary data. Housing costs are notoriously difficult to estimate. With the TOPAZ model the literature suggests that it has often been so difficult to estimate the benefits of location or interaction that only costs were used. Yet, both versions of TOPAZ would certainly have given different results if some locational advantage variable had been used to yield a "net" location cost variable for the location cost term in the objective function.

Finally there is the computational problem. The GAMS package *(15)* was used for all of the Archerville tests reported here. The linear formulations were run on an IBM PC with 640K of memory and a hard disk drive. These runs took just a few minutes each. The nonlinear formulations were problematic on the PC; some took 2 or more hours to solve, and others would not run at all. Finally, a version of GAMS for the IBM 3081 GX mainframe was used for the nonlinear formulations. In the combined model there were 622 variables in the objective function. The objective function for the final nonlinear version of TOPAZ, alone, had 110 variables, but, if there were a 30-zone region to be analyzed, the objective function in the nonlinear TOPAZ model would have 3,660 variables. This is a rather sizable problem, and yet a 30-zone spatial interaction model is really too highly aggregated for most policy analysis purposes. Further, the examples presented used only two household types and no housing stock consideration. Current transportation and location modeling applications tend to have from 200 to 300 zones. With no increase in activity types, 250 zones would yield 250,500 variables in TOPAZ. The model formulations that combine location and trip assignment are even larger. Problems of this size are really quite impractical for direct solution. The problems of solving optimizing models of a realistic (from the applications point of view) size can be dealt with by decomposition procedures if it is desirable to maintain the mathematical programming formulations. The possibility of transforming programming models into spatial interaction models as briefly mentioned earlier offers another avenue of approach. Both of these approaches will be examined in future research.

Despite these concerns there are several important points to be learned from these experiments. Perhaps the most important is that developing these model formulations and then testing their behavior gives wonderful insight into various hypotheses about locational behavior. The eminent sensibility of describing locational behavior as an optimizing process is beyond reproach. The effects, and general importance, of constraints in such formulations became clearly evident in these experiments. At the same time the experiments clearly illustrated the need for inclusion of dispersion terms in such models. The inference is that although locational behavior may be said to be, in principle, an optimizing process, in actuality there are obviously other factors that result in a dispersion of locations around a simple "least-cost" optimum. Yet the optimizing process provides a model-building rationale that can be particularly helpful in understanding the implications of model structure and can thus, in turn, be expected to improve modeling practice as well.

REFERENCES

1. S. Putman. Future Directions for Urban Systems Models: Some Pointers from Empirical Investigations. In *Advances in Urban Systems Modelling* (B. Hutchison and M. Batty, eds.), North-Holland, Amsterdam, The Netherlands, 1986.
2. S. Putman. *Integrated Urban Models.* Pion Ltd., London, England, 1983.
3. M. Ben-Akiva and S. Lerman. *Discrete Choice Analysis.* MIT Press, Cambridge, Mass., 1985.
4. Y. Sheffi. *Urban Transportation Networks.* Prentice-Hall, Inc., Englewood Cliffs, N.J., 1985.
5. A. Anas. *Residential Location Markets and Urban Transportation.* Academic Press, New York, 1982.
6. A. Wilson, J. Coelho, S. Macgill, and H. Williams. *Optimization in Locational and Transport Analysis.* John Wiley & Sons, Chichester, England, 1981.
7. D. Boyce and R. Eash. Application of a Combined Residential Location, Mode, and Route Choice Model to Strategic Planning for the Northeastern Illinois Regional Transportation Authority. Presented at 66th Annual Meeting of the Transportation Research Board, Washington, D.C., 1987.
8. P. Prastacos. Urban Development Models for the San Francisco Region: From PLUM to POLIS. Presented at 64th Annual Meeting of the Transportation Research Board, Washington, D.C., 1985.
9. J. Brotchie. A General Planning Model. *Management Science,* Vol. 16, 1969, pp. 265–266.
10. R. Sharpe and J. Brotchie. An Urban Systems Study. *Royal Australian Planning Institute Journal,* Vol. 10, 1972, pp. 105–118.
11. J. Brotchie, J. Dickey, and R. Sharpe. *TOPAZ.* Lecture Notes in Economics and Mathematical Systems 180. Springer-Verlag, Heidelberg, Federal Republic of Germany, 1980.
12. R. Sharpe, B. Wilson, and R. Pallot. Computer User Manual for Program TOPAZ82. Division of Building Research, Commonwealth Scientific and Industrial, Research Organisation, Highett, Victoria, Australia, 1984.
13. J. Murchland. *Some Remarks on the Gravity Model of Trip Distribution and an Equivalent Maximizing Procedure.* LSE-TNT-38. London School of Economics, London, England, 1966.
14. A. Wilson. A Statistical Theory of Spatial Distribution Models. *Transportation Research,* Vol. 1, 1967, pp. 252–269.
15. D. Kendrick and A. Merraus. *GAMS, An Introduction.* The World Bank, Washington, D.C., 1985.

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Urban Form Optimization System: A Computer-Aided Design and Evaluation Tool for Assisting the Investigation of Interrelationships Between Land Use and Transportation

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Solving traffic congestion problems has long been a major objective of urban transportation studies. Neither construction nor operations management can totally solve congestion problems economically, efficiently, and equitably. Urban congestion problems can be reduced only if a better understanding of the long-term interrelationships between land use and transportation is achieved. The Urban Form Optimization System (UFOS) represents an initial attempt to develop a computer-aided design and evaluation tool to aid investigations of interrelationships between land use and transportation. UFOS contains a land use–network editor, an integrated land use–transportation simulation model, an interactive graphic mapping module, and a multicriteria evaluation module. These modules are linked together so they can support an interactive graphic design and evaluation process. To date UFOS has been proven effective in designing and evaluating land use–transportation alternatives in the classroom. UFOS's major functions are described in this paper, and some examples that illustrate its capabilities are provided.

Solving traffic congestion problems has long been a major objective of urban transportation studies. Neither construction nor operations management can totally solve congestion problems economically, efficiently, and equitably. Urban congestion problems can be reduced only if a better understanding of the long-term interrelationships between land use and transportation is achieved. Traditionally, such long-term interrelationships have been investigated using an integrated land use and transportation simulation model *(1–5)*. There are four major weaknesses in these studies. First, they usually do not use equilibrium solutions. Second, they are limited in the number of alternatives generated and evaluated. Third, they produce large quantities of data that are hard to comprehend and interpret. The last and most important weakness is that they usually lack an explicit multicriteria evaluation component. For these reasons, an improved computer-aided design and evaluation simulation model is needed to help in better understanding the complexities of an urban system.

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URBAN FORM OPTIMIZATION SYSTEM

The Urban Form Optimization System (UFOS) is an interactive graphic computer program that is designed to allow a user to formulate and test a wide variety of ideas about the design of a city. It allows a user to change an existing land use pattern or to change the capacity of various links in an existing transportation network (or to change both simultaneously) and then immediately calculate values for a set of criteria that is used to evaluate how well the resulting land use–transportation alternative performs in relation to other alternatives. It supports a man-machine intuitively guided design process that consists of the generation and evaluation of a series of alternative designs. The overall objective is to maximize performance in relation to multiple criteria. It is operational on a CDC Cyber 180/855 computer and uses the TEMPLATE graphics program. UFOS has four main features: it (a) is user friendly, (b) is interactive and graphic, (c) includes equilibrium conditions, and (d) uses a multicriteria evaluation technique. These features are present in four individual modules:

1. The UFOS1 module supports input data editing, such as task title, land use pattern, network attributes, and other parameters. UFOS1 has a built-in data consistency checking function to help the user avoid input errors.
2. The UFOS2 module performs land use–transportation simulations, given a distribution of basic employment and a transportation network. It allocates population and service employment to zones and loads the transportation network with journey-from-work trips. It is basically an integration of a Lowry-type land use allocation model and an equilibrium traffic assignment model. It uses an iterative technique that adjusts both land use and network loads so that an equilibrium condition results from the computations of the assignment model. Congestion is the main link between land use and transportation in the model. As congestion rises, link speeds are reduced and the land use allocation process changes accordingly.
3. The UFOS3 module generates graphic displays using the input data to and output data from the simulation model, such as basic employment distribution, population distribution, network loading, and congestion patterns. It also allows changes between the previous design and the current design to be

displayed. UFOS3 employs TEMPLATE graphics subroutines to draw maps on a Tektronix graphics terminal and hardcopy machine. Figure 1 shows examples of graphic displays that can be generated by UFOS3.

4. The UFOS4 module performs the multicriteria evaluations and displays the results to help the user identify superior designs. UFOS4 automatically records up to 13 areawide performance criteria calculated from UFOS2. For most applications these 13 criteria are related to broad objectives in a hierarchical manner:

	+ Efficiency --	+ V/C (less is better)
		+ WTT (less is better)
		+ WTS (more is better)
		+ NWTT (less is better)
		+ NWTS (more is better)
		+ AENG (less is better)
Total Worth - of Design	+ Economy --	+ COST (less is better)
		+ SMP (less is better)
		+ SME (less is better)
		+ TRAN (more is better)
	+ Equity ----	+ ACCP (more is better)
		+ ACCS (more is better)
		+ ACCN (more is better)

where

V/C = the average of the link-specific volume-to-capacity ratios for the entire network.

WTT = the areawide average work-trip travel time in minutes.

WTS = the average work-trip travel speed in miles per hour.

NWTT = the average non-work-trip travel time in minutes.

NWTS = the average non-work-trip travel speed in miles per hour.

AENG = the average gasoline cost in dollars.

COST = the combined arterial and freeway network construction cost derived from the equivalent lane-miles of each facility type.

SMP = the second moment of the total population distribution. Larger values indicate more dispersed distribution patterns. For UFOS design problems, it is assumed that less is better for the SMP in order to capture the cost-reduction benefits of compact urban forms. More important, lower values avoid unreasonably dispersed population distributions that have few agglomeration economies.

SME = the second moment of the total employment distribution. As is the case for SMP, smaller values are preferred.

TRAN = transit ridership share as a percentage of total person trips.

ACCP = the sum of all zone-specific accessibility indices to total population.

ACCN = the sum of all zone-specific accessibility indices to non-location-oriented service employment.

ACCS = the sum of all zone-specific accessibility indices to location-oriented service employment.

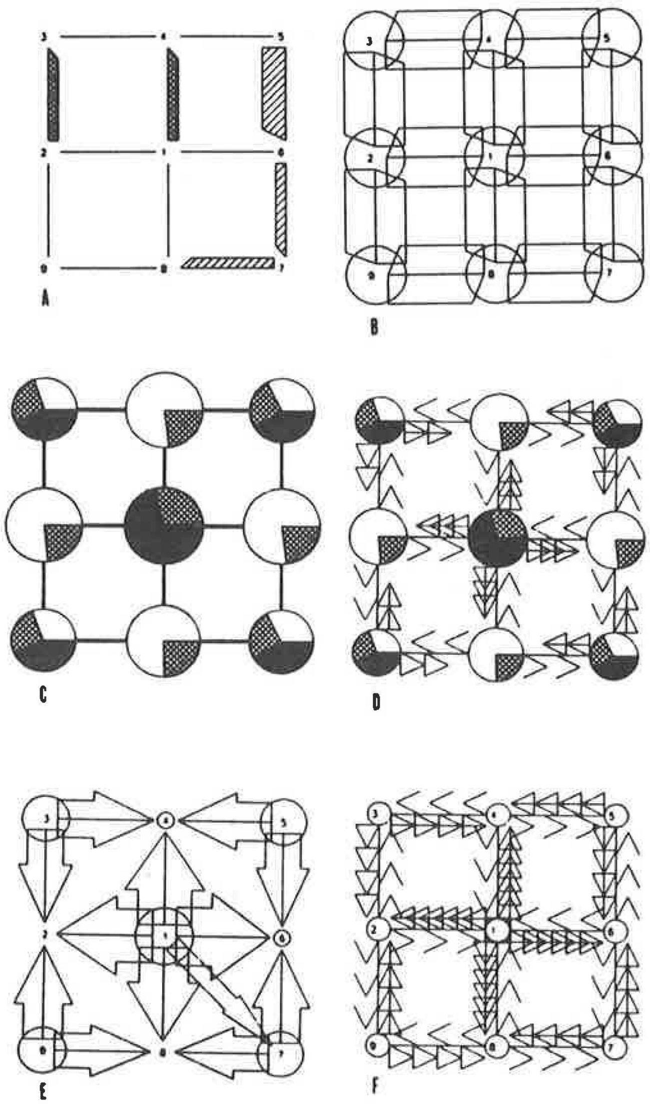

FIGURE 1 Examples of UFOS3 graphics: A, link attribute changes; B, link attributes; C, land use (employment and population); D, land use and congestion; E, origin-destination flows; and F, link congestion.

The design problem is to find a way to raise the values of the six more-is-better criteria while reducing the values of the seven less-is-better criteria. In addition to these 13 criteria, there are 2 other criteria that are not included in the concordance analysis but are nevertheless important indicators of network efficiency:

OLL: the number of overloaded links and
ULL: the number of underloaded links.

The multicriteria evaluation is performed by using concordance analysis *(6, 7)*. This technique makes it possible to deal effectively with multiple, conflicting criteria that are always present in land use–transportation problems. Basically, concordance analysis involves normalizing a project effects matrix, devising sets of relative importance weights for the criteria, and comparing each alternative with all other alternatives. It produces a ranking of the alternatives and indicates those that are nondominated. These are usually referred to as "best-compromise" alternatives because they have been found to be generally superior with respect to all of the multiple viewpoints or value sets represented by the sets of relative importance weights used in the analysis. The essence of the concordance analysis results is shown graphically in Figure 2.

ILLUSTRATIVE EXAMPLE

In this section is provided an illustrative example drawn from a network design exercise in which five alternative network designs were generated and evaluated. Given several designs and weighting schemes, the purpose of a design and evaluation process is to identify a best-compromise design with respect to several different and conflicting criteria. The city shape used is defined by a grid and radial network shown in Figure 3. A total of 30,000 basic jobs are allocated first. One-third of these jobs are located at the center (Node 1) of the network. The other 20,000 basic jobs are equally distributed among four nearby nodes (3, 5, 7, and 9). The initial link capacity is set at 800 vehicles per hour (vph) for each grid and 1,300 vph for each radial link. For all internal links, a capacity of 2,000 vph is used. In addition, a transit network is evenly spread over the city.

The land use attractiveness factors are asymmetric as given in Table 1. Given these initial land use and network input data, UFOS2 generated the land use and network congestion pattern shown in Figure 4. In the model, the 30,000 basic jobs internally generate a total population of 120,000 and a service employment of 30,000. A total of 60,000 work trips are loaded on the network and produce considerable congestion.

The resulting land use attractiveness factors are not uniformly distributed. Figure 5 shows the congestion pattern as represented by link-specific V/C ratios. From this map it can seen that the links that are connected to Node 2 are heavily congested. This is because Node 2 has been allocated the

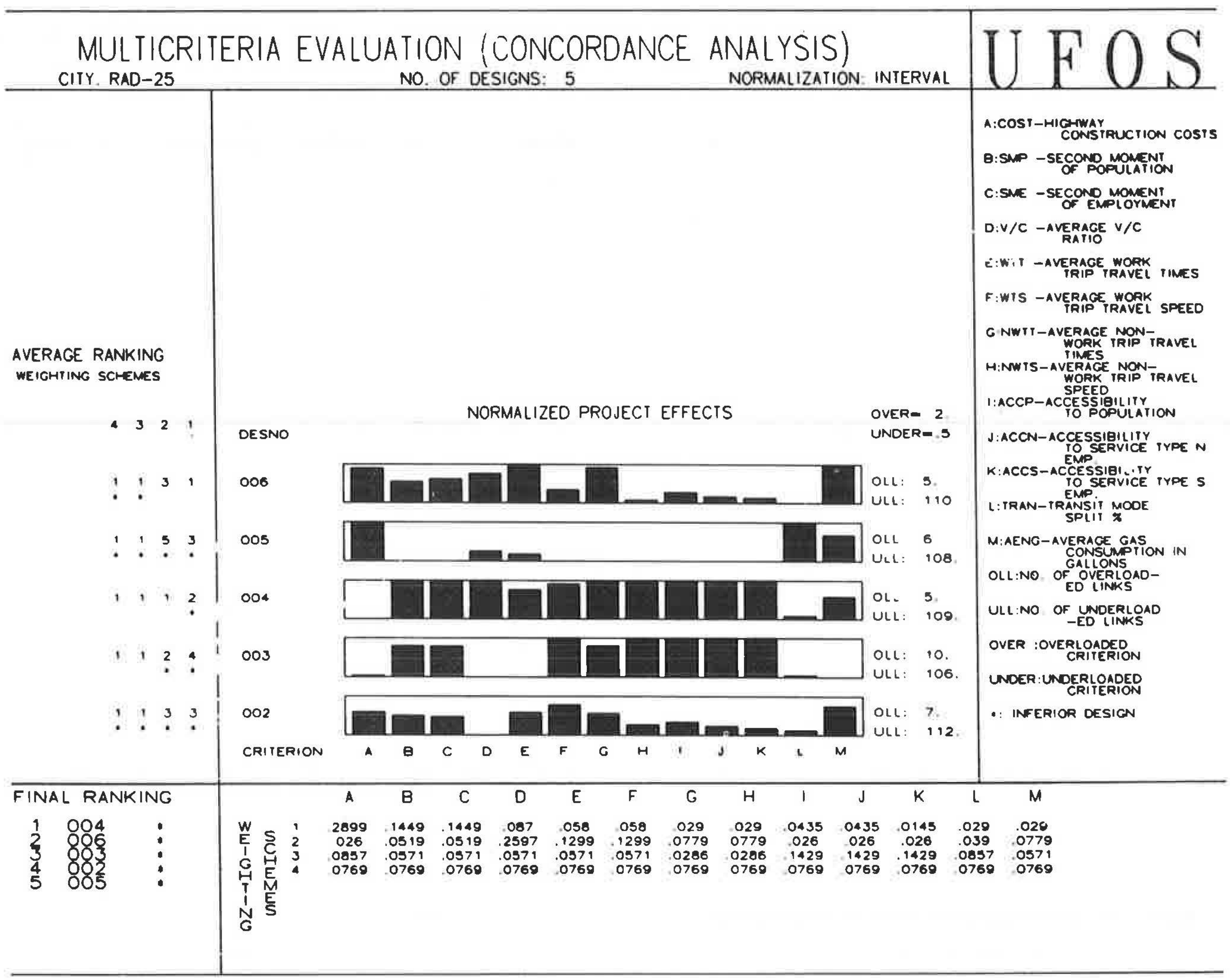

FIGURE 2 Multicriteria evaluation display using concordance analysis results.

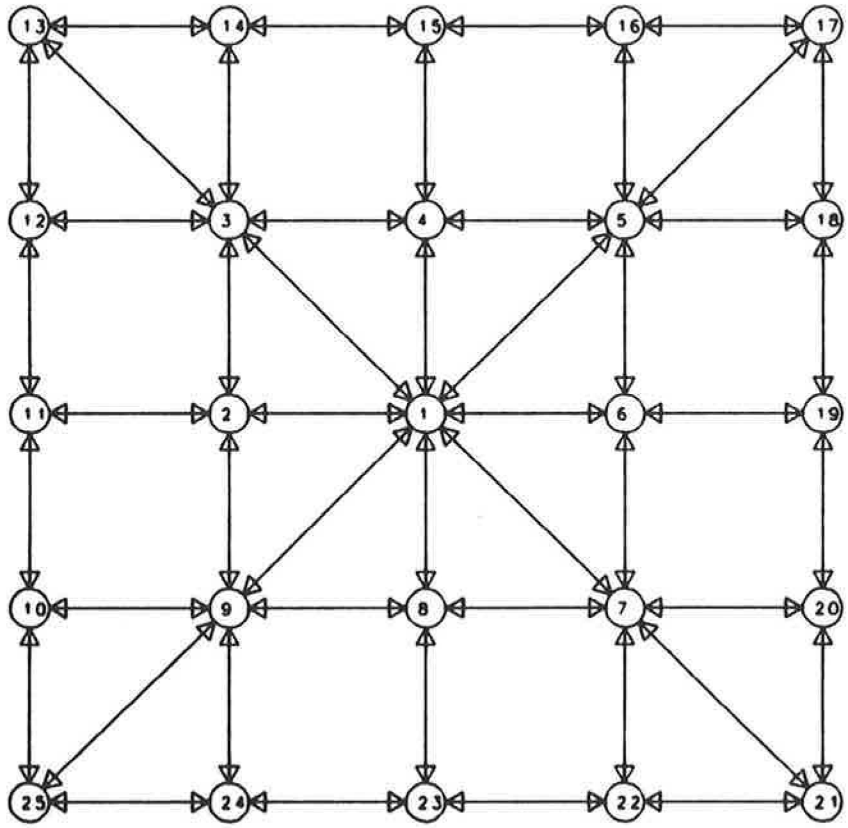

FIGURE 3 Network configuration (Design 1).

TABLE 1 LAND USE ATTRIBUTES FOR ILLUSTRATIVE EXAMPLE

Zone[a]	No. of Basic Jobs[b]	Residential Attractiveness Index[b]	Service-N Attractiveness Index[b]	Service-S Attractiveness Index[b]
1	10,000	100	100	100
2		200	50	50
3	5,000	300	50	50
4		200	50	50
5	5,000	200	50	50
6		200	50	50
7	5,000	200	50	30
8		200	50	50
9	5,000	200	50	50
10		300	50	30
11		400	50	60
12		500	30	50
13		100	70	50
14		100	50	50
15		200	50	50
16		100	50	50
17		400	50	50
18		300	20	50
19		300	50	50
20		100	10	80
21		200	50	90
22		100	50	30
23		100	50	50
24		200	50	50
25		400	50	50

[a]Each node in the network represents a zone in the city.
[b]More is better.

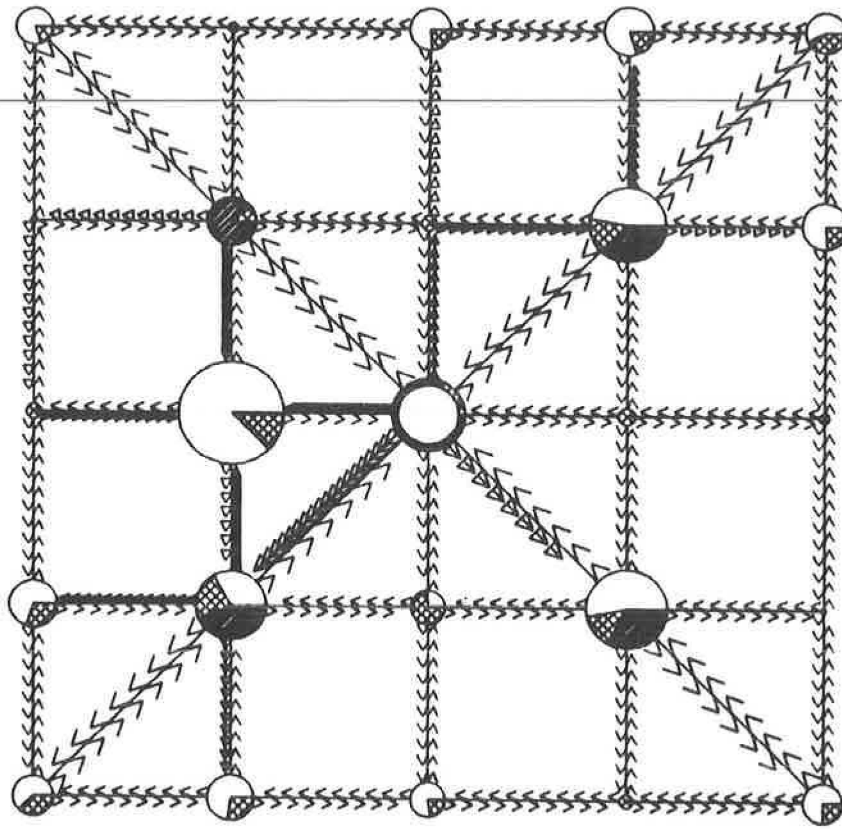

FIGURE 4 Land use and link congestion of base design with loaded network, population, and employment (Design 1).

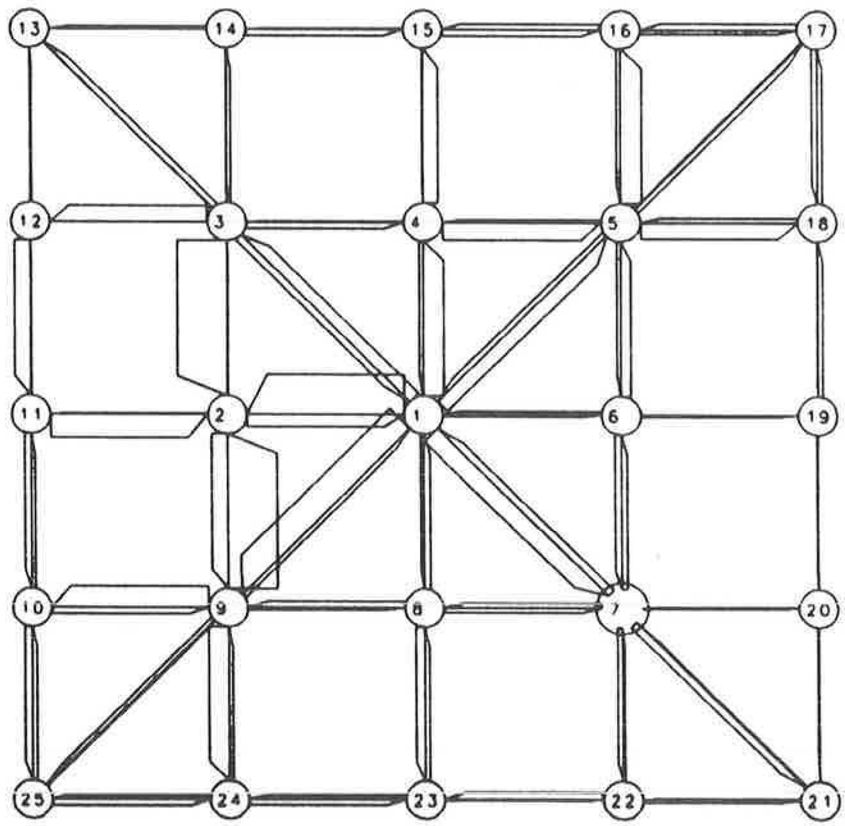

FIGURE 5 Link V/C of base design (Design 1).

largest population and so attracts heavy volumes of work-to-home trips during the evening peak hour. The high V/C ratios (e.g., 3.4, 3.4, and 2.8) on these links indicate that the link capacities are not well matched to the land use pattern in this area.

If the location of basic jobs is kept fixed, one way to relieve the heavy congestion is to change certain link capacities. This can be done by (a) adding capacity, (b) reducing capacity, (c) building new roadway links, and (d) improving the transit network. Increasing link capacities will usually reduce the average network congestion level. But, because construction budgets are normally limited, capacity cannot simply be added to every congested link. Usually, the optimal network design problem involves finding the smallest construction budget that produces the greatest set of benefits.

Solving this problem involves determining how much capacity to add or to delete or from each link and where to do so. Conceptually, there are billions of alternative designs possible even for this small network. In reality, only a few of these designs will be economical, efficient, and equitable. However, the more alternatives that can be generated and evaluated, the more likely it is that a truly superior solution will be found.

For the example, five designs (2–6) were generated. All of these alternative designs represent a conventional reaction to congestion in that additional capacity was added to congested links. Each of the designs represents a different way of dealing with the same problem. The land use pattern was always considered in resetting the link capacities. Some selected results of these designs are shown in Figures 6–9. The values calculated for the 13 criteria used to evaluate the five designs are given in Table 2. The overall evaluation display from UFOS4 is shown in Figure 2.

Figure 6 (Design 2) shows the land use and congestion pattern that was produced by adding capacity to congested links as shown in Figure 7. By comparing Figure 4 (Design 1) and Figure 6 (Design 2), it can be quickly seen that most of the heavy congestion in Design 1 is no longer present in Design 2. Still, there are several congested links in Design 2 that need further attention. The large increase in population and employment at Node 8 that resulted from the link capacity additions made to the network of Design 1 can also be seen.

Figure 8 (Design 4) shows the land use and congestion results of adding capacity to the first roadway ring (shown in Figure 9). Comparing Figures 4, 6, and 8 reveals several congestion levels and land use differences. Design 4 still has some congestion problems but they are relatively minor compared with those of Design 1. Designs 5 and 6 used different capacity change patterns, but neither produced results that were better than Design 4 (Figure 8).

Four different weighting schemes were generated to reflect the different viewpoints that decision makers might bring to this problem. The first weighting scheme is economy oriented, the second is efficiency oriented, and the third is equity oriented. The last weighting scheme assumes that all criteria are equally important. These weighting schemes are included in the multicriteria evaluation display (Figure 2). Given the criteria values (Table 2) for each of the six designs and the four weight sets, concordance analysis first sequentially evaluates

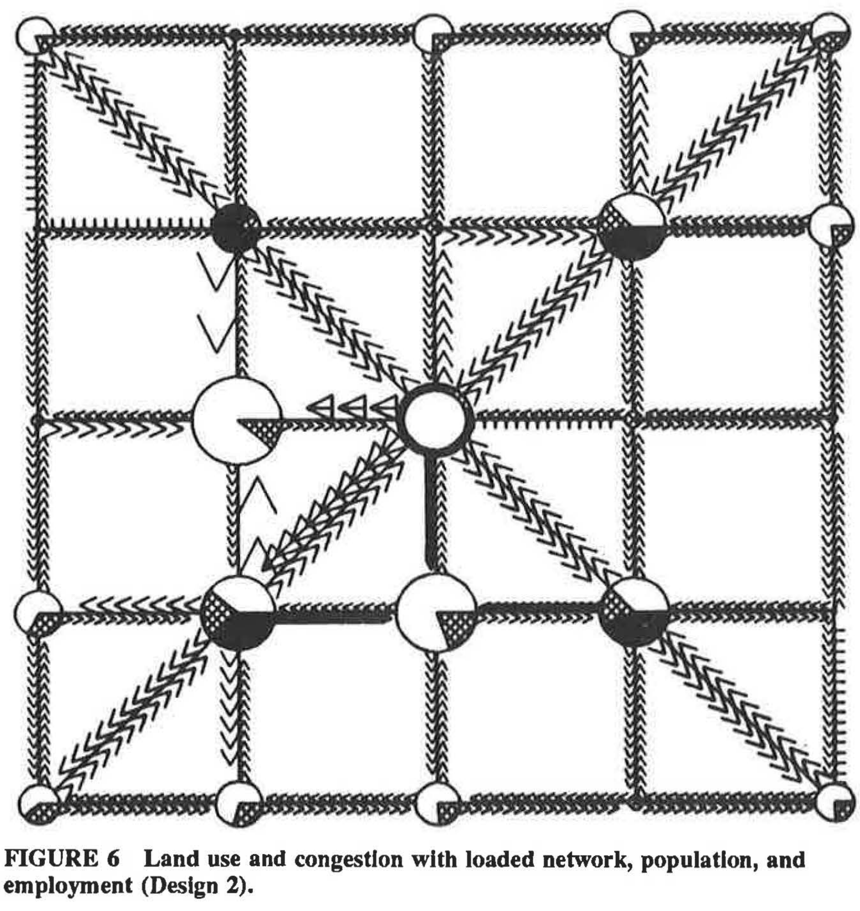

FIGURE 6 Land use and congestion with loaded network, population, and employment (Design 2).

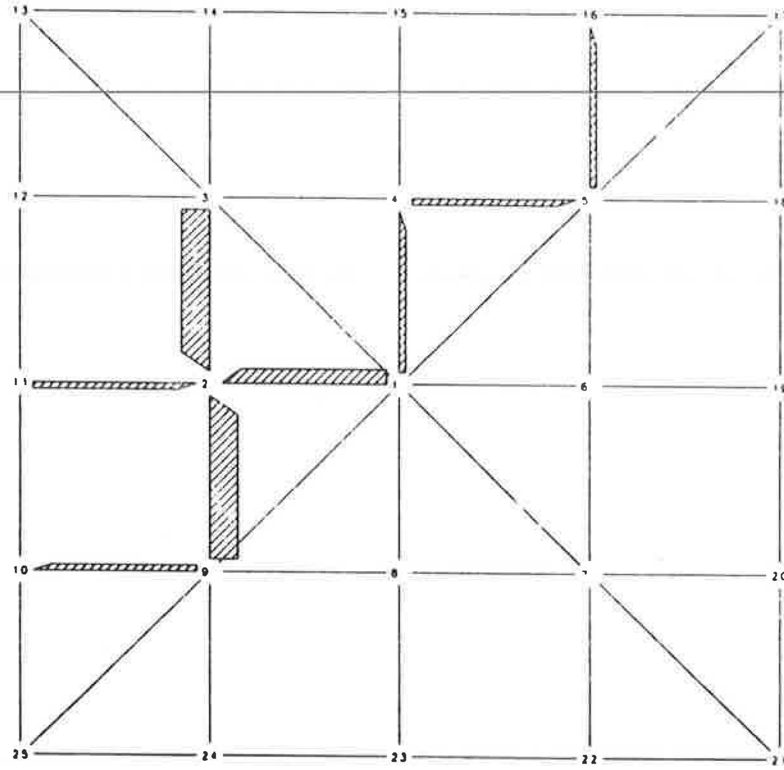

FIGURE 7 Link capacity changes between Designs 1 and 2.

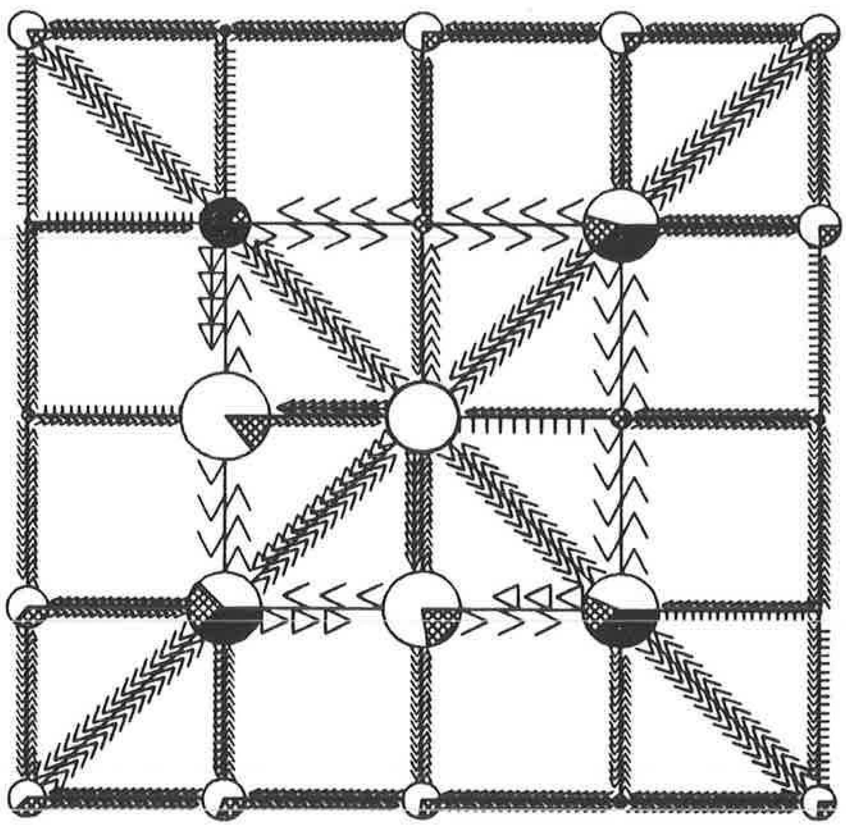

FIGURE 8 Land use and link congestion with loaded network, population, and employment (Design 4).

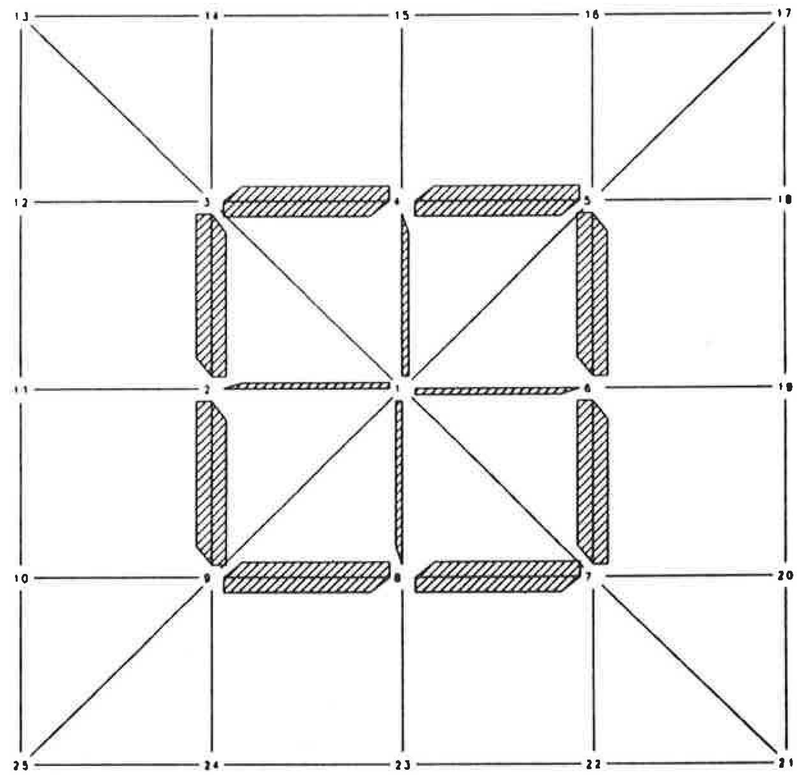

FIGURE 9 Link capacity changes between Designs 1 and 4.

TABLE 2 AREAWIDE PERFORMANCE CRITERIA VALUES FOR ONE BASE AND FIVE ALTERNATIVE DESIGNS

Performance Criterion	Base (starting) Design 1	Alternative Design 2	3	4	5	6
COSTS	1280	1731	2216	2206	1413	1496
SMP	51853	48744	47219	46193	51277	48503
SME	20115	19578	19237	18995	20088	19421
V/C	0.47	0.38	0.38	0.34	0.37	0.35
WTT	22.06	17.55	18.99	17.13	18.57	16.53
WTS	5.65	6.69	6.85	6.78	6.12	6.37
NWTT	10.21	10.21	10.15	10.10	10.35	10.12
NWTS	18.41	19.76	22.69	22.53	18.70	19.00
ACCP	388.97	423.42	468.38	468.29	400.37	418.72
ACCN	113.06	121.88	150.98	151.86	112.85	119.21
ACCS	116.09	122.81	152.98	153.57	116.17	120.90
TRAN	16.34	15.38	15.22	15.29	18.57	15.14
AENG	0.73	0.62	0.71	0.64	0.63	0.59

the alternative designs relative to each weight set. Finally, all designs are evaluated and ranked in relation to all weight sets. The details of this calculation are available in other published papers [e.g., Giuliano *(7)*].

Using UFOS4, the user can obtain a display of the evaluation as shown in Figure 2. In the center of this display, bar charts of normalized criteria values are displayed and the associated number of overloaded and underloaded links is shown for each design. The average rank of each design of the four weighting schemes is shown on the left side of the display. These average ranks are aggregated and averaged to produce the final ranking that shows the best-compromise design (Design 4). Ideally, the design that is ranked highest and is nondominated for every weighting scheme is the best one. However, in many cases, this result is not easily achieved and a more detailed examination of the sensitivities of the weighting schemes is necessary.

In this example, the interval normalization method is used and Design 4 is ranked highest. None of the designs is totally nondominated for all weighting schemes. However, Design 4 is nondominated for Weighting Schemes 1–3 and is clearly the best-compromise design of this set. Although Design 4 is the second most costly alternative, it produces better marginal benefits for the other criteria than do the other designs. Design 4 is dominant using only the cost-oriented weighting scheme. This indicates that when the weight on cost is moved down to as little as 0.3, Design 4 will be dominated by Design 6, which costs considerably less. This is an example of the type of trade-off information that can be obtained from the multicriteria evaluation display. Selection of the proper weighting schemes that will allow the development of a consensus among decision makers is, as always, the major task in selecting a preferred design.

It is not suggested that the results from concordance analysis be accepted and used alone for decision making. They simply represent an objective evaluation for use in a decision-making process. Before a final decision is reached, such results need to be carefully examined. UFOS has been designed to facilitate an effective design evaluation process and to help the user more clearly identify the often mysterious trade-offs that exist in any multicriteria evaluation process.

DISCUSSION OF RESULTS

In this paper has been described the initial version of a new computer-aided design and evaluation tool that is currently being used to investigate the interrelationships between land use and transportation at the University of Washington. UFOS can be used to generate and evaluate a wide range of designs effectively and efficiently. A small-scale network design problem has been used to illustrate its capabilities with reference to five alternative designs. Several maps were developed to display data on the spatial relationships of the land use pattern and the network performance attributes of each design. The congestion pattern is easily seen on these maps. Concordance analysis is used to identify the best-compromise design of the five considered. Four different weighting schemes were used in the evaluation.

It is suggested that use of this computer-aided design and evaluation tool will help practicing professionals find a more efficient and effective approach to dealing with complicated multicriteria land use–transportation problems. UFOS is currently being used to conduct a variety of experiments that are designed to investigate and identify land use–transportation interrelationships more clearly than has been possible previously. For example, the results from 120 designs for a small test problem are being examined to see if there are any strong relationships among the 13 criteria used for evaluation. If strong relationships can be found, they may be powerful aids in the design process for networks that are too large for the practical application of mathematical programming techniques.

As it stands, UFOS is a tool that can be used to investigate a wide variety of questions in a laboratory setting. Various parts of the problem can be held constant or allowed to vary. Interpretation of results is greatly eased by the readily available graphics. Finally, evaluation of alternatives, an often underdeveloped part of the planning process, is given a major role in the design process.

REFERENCES

1. G. Hemmens. Experiments in Urban Form and Structure. In *Highway Research Record 207*, HRB, National Research Council, Washington, D.C., 1967, pp. 32–41.
2. J. Schneider and J. Beck. Reducing the Travel Requirements of the American City: An Investigation of Alternative Urban Spatial Structure. In *Transportation Research Record 499*, TRB, National Research Council, Washington, D.C., 1974, pp. 12–33.
3. R. Peskin and J. Scofer. *The Impacts of Urban Transportation and Land Use Policies on Transportation Energy Consumption*. DOT-TST-77-85. U.S. Department of Transportation, 1977.
4. R. Sharpe. Improving Energy Efficiency in Community Land-Use-Transportation Systems. *Environment and Planning A*, Vol. 12, 1980, pp. 203–216.
5. R. Peiser. Land Use Versus Road Network Design in Community Transport Cost Evaluation. *Land Economics*, Vol. 60, No. 1, 1984, pp. 95–109.
6. H. Voogd. *Multicriteria Evaluation for Urban and Regional Planning*. Pion Limited, London, England, 1983.
7. G. Giuliano. A Multicriteria Method for Transportation Investment Planning. *Transportation Research A*, Vol. 19, 1985, pp. 29–41.

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Cost-Efficiency of Intercity Bus Technology Innovations

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Intercity bus transportation in Canada is in need of innovations to reduce costs and enhance passenger and cargo revenues. Higher-capacity buses, with improved passenger comfort and enlarged cargo space, could replace the existing standard coach in serving high traffic loads and thus eliminate the need for dispatching two or three buses simultaneously. Research is reported on the cost-efficiency of three new bus technologies vis-à-vis the standard coach, namely an articulated bus, a rigid body double-deck bus, and an articulated double-deck bus. Variations of bus design options in terms of costs and seating densities are also defined. Six routes in the Quebec-Windsor corridor are used for the assessment of bus technology options. Two analytical models were used for cost-efficiency analyses. The incremental supply and cost model compares relative cost-efficiencies for simulated passenger loading levels. The route supply and cost model estimates the supply of buses required to serve demand and also calculates unit costs for specific routes. Results reported here indicate the relative potential of high-capacity bus options for cost savings as well as operational factors related to their application.

Intercity bus transportation in Canada is in need of productivity improvements to offset the effects of cost escalation and changes in ridership. This low-cost and largely self-supporting mode has experienced a significant decline in ridership and profit in recent years. After almost constant ridership throughout most of the 1970s, the intercity bus mode experienced a net decline of more than 12 percent during the 1980–1984 period *(1)*. Its market share has also been declining over the years. In recent years its profit has declined in actual as well as constant dollars *(2)*.

The intercity bus industry in Canada is concerned about the declining profit and market share trend. The impacts of cost escalation and an unfavorable passenger market situation are obvious in the form of declining profit, given that about 68 percent of this industry's revenues are earned from scheduled passenger services (versus 10 percent from charter, 17 percent from parcel express, and 5 percent from other) (1982 figures, rounded) *(1, 3)*. Clearly, this industry needs cost-effective means of improving service and curbing its escalating costs.

Among other innovations for increasing productivity and efficiency, vehicular technology innovations are expected to play a major part because these could improve ridership as well as the cost picture. On the passenger side, surveys show severe passenger dislike of the standard coach. More than 60 percent of respondents complained of excess vibrations and lack of work space during transit. About 50 percent complained of excess jolts and rough rides, noise, and lack of ventilation *(4, 5)*. Major difficulties also exist in controlling labor and other costs. Clearly, cost-effective means are required for favorable cost and service outputs.

Technology-based opportunities exist for improving the service and productivity of the intercity bus industry. In addition to improving the standard coach (e.g., a wider body with improved suspension and energy efficient power plant), there is a need in Canada to develop and operate large (high-capacity) buses on routes that normally require overload buses.

Sufficient evidence is available of the role for higher-capacity, more-comfortable buses as replacements for the existing standard coaches in serving peak loads. For example, the three largest intercity carriers in Canada operate as many as 200 buses and employ some 450 drivers to operate second or overload buses. On numerous routes, two or three buses are dispatched simultaneously to meet surges in demand. On such high-density travel routes, an estimated 30 percent of bus departures are overload buses. Such duplication can be eliminated by higher-capacity coaches *(4)*.

In addition to serving high traffic loads per departure on well-traveled routes and eliminating the need for second or overload buses during peak times, high-capacity buses have the potential to provide improved comfort and enhanced space for their users. At appropriate usage levels, substantial labor and fuel efficiencies are achievable *(6)*. Another important advantage of large buses would be their extra (enlarged) valuable cargo and baggage capacity *(4)*.

Unlike that of the air transportation industry, deregulation of the bus industry in Canada is not expected to reduce the demand for high-capacity vehicles because the intercity bus service structure is likely to intensify on well-traveled corridor routes. Increased peaking of traffic coupled with market concentration is not likely to lessen the need for high-capacity use. Because high-capacity buses would replace overload or extra sections, which are dispatched simultaneously, their use would not affect user perception of frequency of service.

This paper ia a report on an investigation of the cost-efficiency of those technologies of the intercity bus that look most promising and that should be the focus of further research, development, and implementation. Canada's highest density corridor, the Quebec-Windsor corridor, is used in analyses as a site for cost-efficiency research studies.

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BUS TECHNOLOGY INNOVATIONS: HIGH-CAPACITY BUS

In Canada there has been an interest in the development and use of high-capacity buses for intercity service on a number of routes that normally rely on extra (overload) buses to serve demand during peak periods. A demonstration of technology and user acceptance features has already been completed on a European-built articulated bus. Follow-up activity is under way to develop and test an articulated bus for intercity scheduled service and charter operations. The manufacturer of this vehicle (Prevost) already has technical cooperation and financial assistance from the relevant agencies of the federal government including the Department of Regional Industrial Expansion (DRIE), Transport Canada, and the government of Quebec *(6)*. At present, the concept of a high-capacity double-deck coach is under study at Transport Canada *(7)*.

Research on the cost-efficiency of the various design options in active service contexts has been regarded as essential before their final development and production. This paper covers highlights of a research study on the cost-efficiency of the following new technologies vis-à-vis the existing standard coach for service in the Quebec-Windsor corridor *(8)*.

1. An articulated bus,
2. A double-deck bus, and
3. An articulated double-deck bus.

A summary of the most important characteristics of each of the bus technology concepts, including the existing standard coach, is given in Table 1. For each bus type, a range of seating capacity is defined. Because there are options in seat throw (i.e., distance between seats), seating capacity can be varied for intended space per passenger.

TABLE 1 COMPARISON OF BUS SPECIFICATIONS *(8)*

Design Class	Dimension (m) H	W	L	Seating	Cost (000s) in 1982 Dollars	No. of Axles
Single deck	3.3	2.5	12	43–47	200	3
Articulated single deck	3.5	2.5	18	61–80	300–400	4
Articulated double deck	4.0	2.5	18	100	500	4
Double deck	4.0	2.5	12	61–80	350–400	3

The articulated single-deck and the articulated double-deck buses are 50 percent longer than the standard coach. The double-deck bus, on the other hand, has the same length as the standard single-deck coach. In all cases, the width of the bus is the same as that of the standard coach. In this research, because of the focus on significant capacity gain, the option of a wider single-deck standard coach was not analyzed.

The maneuverability and stability characteristics of new bus designs can be studied in detail only through actual road tests after the manufacture of a selected type or types of buses. However, theoretical and computer simulations suggest that no problems are likely to be encountered. Although the new design concepts are intended to be highly advanced in terms of technology components, generally similar designs have been in use in Europe. Therefore, from a technical performance perspective, no problems are expected. Only small structural changes to terminals would be required to allow these buses to be maneuvered *(4, 5)*.

ESTIMATION OF COSTS

Intercity bus transportation costs are classified here as equipment acquisition, driver, operation, maintenance, and administration costs. Table 2 gives the percentage of total bus transportation costs accounted for by each category, based on the cost experience of the Voyageur bus company *(9)*. Selected major carrier costs and operations data are noted in Table 3 *(10)*.

Examination of these data suggests that technical efforts are required to improve costs of equipment acquisition, operation,

TABLE 2 TYPICAL INTERCITY BUS CARRIER COST COMPOSITION *(8)*

Cost Item	Percentage of Total Cost
Bus unit leasing	11.3
Driver	
Wages and benefits	41.4
Expenses	2.1
Subtotal	43.5
Bus operation	
Tires	2.1
Fuel	11.9
Insurance	1.5
Licensing	1.2
Miscellaneous	0.8
Subtotal	17.5
Bus maintenance	
Wages and benefits	10.2
Parts	5.4
Cleaning	1.3
Exterior repair	2.0
Other	1.4
Subtotal	20.3
Administration overhead	7.4

TABLE 3 SELECTED MAJOR INTERCITY BUS CARRIER COSTS AND OPERATIONS DATA *(10)*

Item	Value
Capital cost ($)	180,000–200,000
Driver cost ($/km)	0.5–0.6
Interest (%)	14–16
Utilization (km/year)	160 000–240 000
Fuel (L/km)	0.36–0.43
Fuel ($/L)	0.31–0.44
Maintenance cost ($/km)	0.15–0.20
Fuel consumption (km/L)	2.31–2.74
Overhead cost ($/km)	0.12–0.20

NOTE: Dollar amounts are in 1982 dollars.

and maintenance on a unit cost basis. Labor and fuel efficiencies are especially important, and it is contended that, through the use of high-capacity buses, labor and fuel productivity enhancements become cost-effective. The importance of labor productivity can be appreciated from data presented in Table 2. Driver cost amounts to 43.5 percent of total costs. Wages and benefits for bus maintenance account for another 10.2 percent of total costs.

Although intercity bus transportation is fuel efficient relative to other modes, further improvements are achievable for the new vehicles under investigation. Payoffs are important for the industry because fuel costs amount to about 12 percent of total intercity bus transportation costs (Table 2). Fuel costs within the operation and maintenance costs of bus transportation amount to from 15 to 20 percent *(11, 12)*.

Cost estimates for high-capacity options have been developed on the basis of an engineering unit cost approach because there are no statistical cost data available for new bus designs *(8–10)* (Table 4). The capital cost of an articulated bus is estimated to be approximately twice that of a standard bus. The double-deck bus is estimated to cost the same amount as an articulated bus. The capital cost of these buses is estimated to range from $300,000 to $400,000 (1982 dollars). Only one cost for the articulated double-deck bus, $500,000, is used in this research in order to keep trade-off analyses to a manageable level.

Advanced-technology bus design, through the use of microelectronics, improved materials, and other design features, is expected to reduce operating costs (such as those of fuel consumption) and maintenance costs *(11–13)*. Because fewer units of the high-capacity bus will be required to carry the same number of passengers as standard buses, it would be cost-effective to install state-of-the-art diagnostic equipment on each unit. This would result in lower maintenance cost per seat-kilometer than the standard bus. Likewise, on the fuel consumption side, although an increase of 10 percent was estimated for both articulated and double-deck buses and a 25 percent increase for the articulated double-deck bus, their larger seating capacity would enhance their fuel efficiency *(9, 10)*.

Driver wages for the high-capacity bus options are assumed to remain the same as those for the standard bus *(9)*. Therefore the driver cost of $0.55/km (1982 dollars) has been considered for all bus technologies. Also, according to the intercity bus operators, the overhead cost would remain the same for both high-capacity buses and the standard bus. Therefore the overhead cost of $0.16/km (1982 dollars) has been used for all technologies. Table 4 gives the details of costs for all bus technologies that are considered in this research.

ROUTES SELECTED FOR BUS TECHNOLOGY ASSESSMENT

The Quebec-Windsor corridor, which is Canada's highest density travel corridor, is generally well served by intercity travel modes *(14)*. Freeway-type road facilities link principal centers in the corridor (Figure 1). The automobile and bus modes offer almost congestion-free service. As previously noted, intercity bus carriers are, however, required to operate extra buses during peak times in order to meet passenger demand. Thus the number of these extra sections could be reduced along with the cost of service if a high-capacity bus were available. These routes, given in Table 5, are therefore appropriate locations for the initial use of high-capacity buses in scheduled service. Intercity distances and origin-destination traffic are given in Table 5. The actual traffic served would be higher because of through traffic that uses the links chosen for this study.

ANALYTICAL MODELS

In theory, an analysis of the economic feasibility of a transport system alternative, such as a new bus technology, should be supported by a complete supply-demand interaction analysis in order to estimate demand for service and level of utilization (i.e., load factors). As noted previously, in the present case, the proposed use of the high-capacity bus as a replacement for the conventional coach is not expected to alter the scheduled (time) frequency of service. That is, passengers would be offered similar frequency of service whether these services were based on standard intercity coach or high-capacity buses. Likewise, there is no change in the fare structure.

There is, however, the prospect of enhanced ridership due to improved comfort and amenities on-board obtainable from the advanced technology of the high-capacity bus designs. Because travel demand estimation models in their present state of

TABLE 4 COST DETAILS OF STANDARD BUS AND TEST BUSES

		Articulated or Double-Deck Bus Option			Articulated
Data Item	Standard Bus	A	B	C	Double-Deck Bus
Bus cost ($)	180,000–200,000	300,000	350,000	400,000	500,000
Seating	45	61/70/80	61/70/80	61/70/80	100
Interest (%)	14–16	14–16	14–16	14–16	14–16
Utilization (km/yr) (000s)	160–240	160–240	160–240	160–240	160–240
Bus cost ($/km)	0.17	0.24	0.28	0.32	0.40
Maintenance cost ($/km)	0.18	0.28	0.32	0.37	0.46
Fuel ($/km)	0.15	0.17	0.17	0.17	0.19
Total bus cost ($/km)	0.50	0.69	0.77	0.86	1.05
Driver cost ($/km)	0.55	0.55	0.55	0.55	0.55
Overhead cost ($/km)	0.16	0.16	0.16	0.16	0.16
Total cost ($/km)	1.21	1.40	1.48	1.57	1.76

NOTE: Dollar amounts are in 1982 dollars.
SOURCE: Based on Nookala *(8)* and Hickling Partners, Inc. *(10)*.

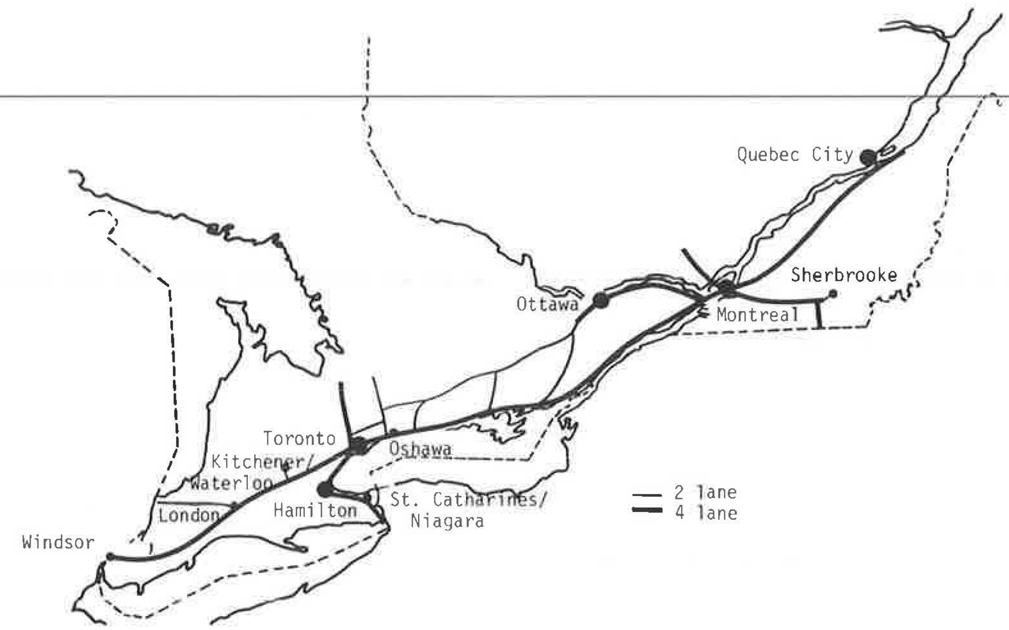

FIGURE 1 Principal intercity highway network, Quebec-Windsor corridor.

TABLE 5 STUDY ROUTES, DISTANCES, AND BUS PASSENGER TRAFFIC

City Pair	Distance (km)	Origin-Destination Passenger Traffic (thousands of one-way trips, 1976)
Montreal–Quebec City	253	702
Montreal-Toronto	540	207
Montreal-Ottawa	195	675
Toronto-Ottawa	395	283
Toronto-Windsor	380	45
Toronto-London	190	135

development cannot assess demand effects of such service attributes, it was considered appropriate to analyze the supply-side variable while holding demand level for the analysis year constant.

Under these conditions, it is necessary to investigate costs for incremental loading levels as well as to investigate costs under route-specific operating and demand conditions. Thus, for the estimation of the cost-efficiency of a new bus unit, two analytical methods were developed:

1. Incremental supply and cost model and
2. Route supply and cost model.

Incremental Supply and Cost Model

This model is intended to simulate passenger loading and calculate unit costs in terms of cost per passenger-kilometer for the bus technology options. This method can thus indicate if there are any levels of passenger demand at which a given high-capacity bus option would be cheaper to operate than the standard bus. Figure 2 is a flowchart of the model. The costs developed previously are used as input to the model.

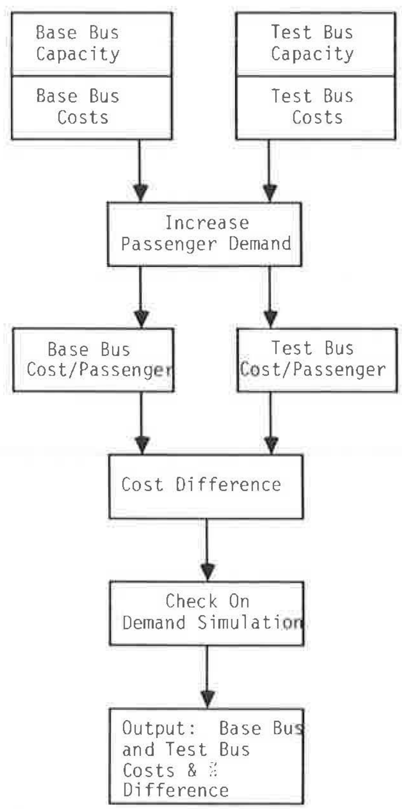

FIGURE 2 Incremental supply and cost model.

Passenger demand is varied from an initial value of 1 to a maximum of 270—a level of demand that is sufficiently high to cover a wide range of service conditions. From the total cost and passenger demand, unit costs are calculated for base and test buses. The next step is to find the difference in cost between the base bus and the test bus and also the percentage difference in passenger-kilometer costs.

The current standard bus is assumed to carry 45 passengers (the average of the intercity operators' fleets). All high-capacity bus designs can then be compared with the baseline bus (45-seat standard coach) and results are plotted in terms of percentage difference in costs per passenger-kilometer.

The significance of the output of this model is that it enables the planner to establish whether there is any role for a proposed high-capacity bus option and also, in relative terms, which option is most attractive for various demand levels.

Route Supply and Cost Model

Figure 3 shows the logic diagram for this model. This model calculates the number of buses required to carry the number of passengers to be served on a specific route. Then, using the input cost information, it calculates the average total cost per passenger-kilometer, cost per bus-kilometer, and total cost per seat-kilometer. The data used are aggregates for the entire year.

Outputs of this model in the form of various unit costs make possible a comparison of the cost-efficiency of relevant bus design options for specific routes. In association with the results of the incremental supply and cost model, these outputs provide a complete picture of the role and cost-efficiencies of intercity bus technology options.

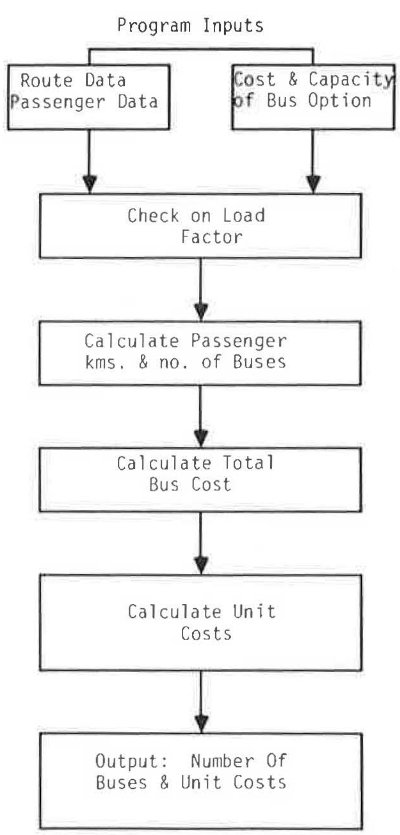

FIGURE 3 Route supply and cost model.

MODEL IMPLEMENTATION AND RESULTS

When the models were implemented, because of the non-availability of recent origin-destination and other passenger data, the bus travel demand for 1976 was used *(8)*. However, according to Statistics Canada catalogs and other sources of data, growth in bus passenger demand on study routes from 1975 to 1985 was rather insignificant. Therefore cost calculations were made using 1976 passenger data (given in Table 5) with 1982 cost estimates.

Because the actual capital cost for the high-capacity buses was not known, a number of cost estimates were developed. As noted in Table 4, these are $300,000, $350,000, and $400,000 for articulated and double-deck bus options. In the case of the articulated double-deck bus, only one estimate of capital cost, namely $500,000, was used for comparative analysis. Comparisons between base bus and test bus were made with all cost calculations of high-capacity bus options.

Figures 4 and 5 show selected results achieved from the incremental supply and cost model applications. As shown in Figure 4, for the double-deck or articulated bus, although the larger size of the vehicle increases the cost by 17 percent, because of the need for a second conventional bus to serve the

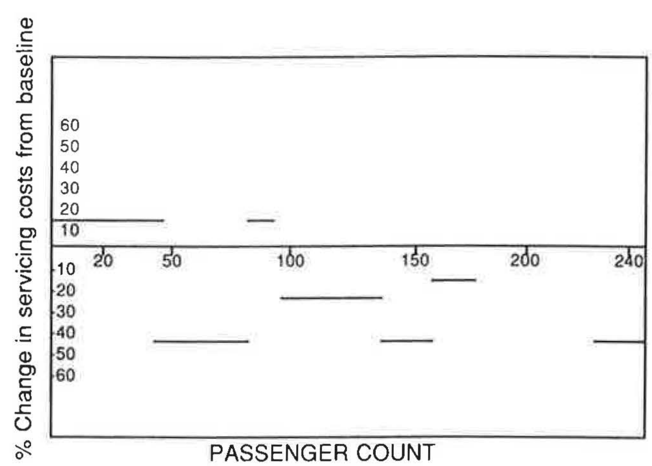

FIGURE 4 Results for 80-seat articulated or double-deck bus (capital cost $300,000).

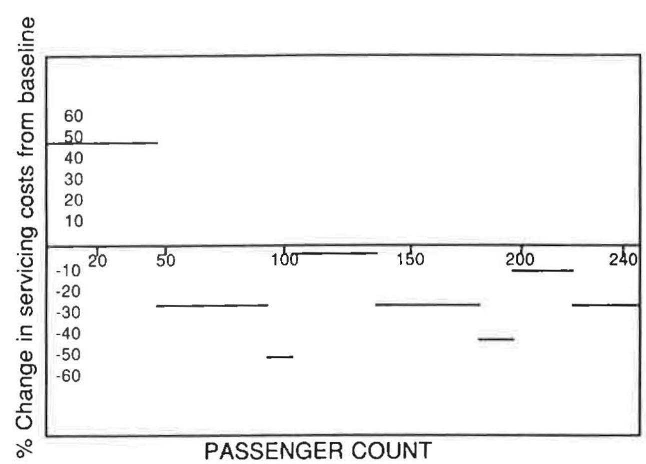

FIGURE 5 Results for 100-seat articulated double-deck bus (capital cost $500,000).

demand, the relative cost of the higher-capacity bus drops by 43 percent compared with that of the standard bus option. As the number of passengers increases, there is an oscillation between regimes of higher (relative) cost and lower (relative) cost with the magnitudes of savings (in terms of cost differences) decreasing with increasing passenger demand.

The results shown in Figures 4 and 5 suggest that in comparison with a standard bus, the regimes of higher cost are less frequent with the larger-capacity bus units and the percentage cost savings are always higher. As the capital cost and number of seats increase (Figure 5), the initial difference between the use of higher-capacity vis-à-vis standard coach increases.

In the case of the articulated double-deck bus ($500,000 capital cost, 100 seats), the initial penalty for using it for low passenger traffic is 46 percent for the first 45 passengers (compared with only 17 percent for the 80-seat, $300,000 bus shown in Figure 4). However, in comparison with the standard coach, after the first 45 passengers, it is always cost-efficient to use the 100-seat jumbo bus. Under conditions of steady and high demand, the 100-seat bus would be a good choice for high-density corridor routes. However, there are only a limited number of such routes in Canada.

Selected results of the route supply and cost model are shown in Figure 6 for the Montreal-Ottawa route. As expected, the standard bus produces the highest cost per passenger-kilometer (e.g., at 70 percent load factor, 3.84 in 1982 dollars). The higher-density seating option of 80 seats for the articulated or the double-deck bus produces the lowest unit cost per passenger-kilometer. Use of the 80-seat articulated (or double-deck) bus is nearly 35 percent more efficient than the standard coach. The articulated double-deck bus (100 seats) has about the same unit cost as the 80-seat high-density seating option for the articulated or the double-deck bus options.

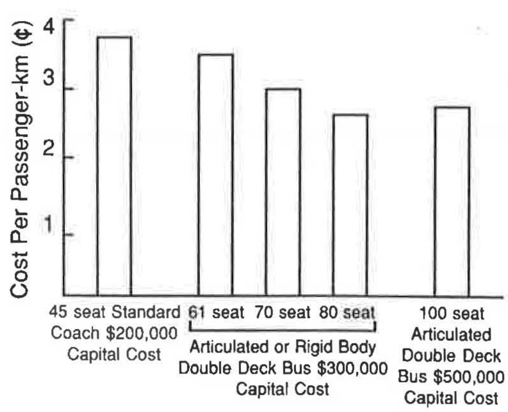

FIGURE 6 Cost-efficiency of bus options for Montreal-Ottawa route (load factor = 70%, 1982 dollars).

At lower but uniform load factors, the relative cost-efficiencies of bus options would be similar to the 70 percent load factor case. Relative cost efficiencies of the bus options can be studied by calculating load factors that result in equal cost per passenger-kilometer (Table 6). As expected, compared with the standard bus, higher-capacity buses require lower load factors to maintain equal cost per passenger-kilometer. However, it should be noted that, in the case of the articulated double-deck bus (100 seats), it would be difficult to maintain reasonably high load factors on a number of routes. Therefore such high-capacity buses are cost-effective on fewer routes than other bus alternatives.

TABLE 6 LOAD FACTORS FOR EQUAL COST PER PASSENGER-KILOMETER

Technology Option	Cost Per Passenger-Kilometer in ¢ (1982 dollars)	Load Factor (%)
45-seat standard coach ($200,000 capital cost)	3.8	70
Articulated or rigid double-deck bus ($300,000 capital cost)		
61 seats	3.8	61.7
70 seats	3.8	53.4
80 seats	3.8	46.1
100-seat articulated double-deck bus ($500,000 capital cost)	3.8	47.9

All large-capacity buses assessed in this study indicate significant potential to reduce the cost of serving demand in the Quebec-Windsor corridor. By adopting high-capacity buses, peaks in travel demand can be served while attractive frequencies are maintained. However, in cases in which the frequency of service is to be reduced because of lower demand, passenger demand would be adversely affected. Therefore these high-capacity buses are best suited to well-traveled routes on which the number of passengers per departure during peak periods is more than the capacity of the standard bus.

CONCLUSIONS

Intercity bus carriers have come to realize that innovations in bus design are needed to reduce costs and enhance passenger as well as cargo revenue potential. Passengers today expect a smooth-riding, quiet, and comfortable mode of surface travel. Thus there is a need to upgrade the design of the highway bus in respect to costs (mainly labor and fuel costs) and ride comfort (i.e., in terms of mechanical noise and vibration, transmission roughness, ventilation, temperature, seating, and on-board amenities). A number of options, namely the articulated, double-deck, and articulated double-deck bus technology options, examined have the potential to satisfy these requirements to varying degrees compared with the existing standard bus. To use high-capacity articulated buses, length restriction laws in the Quebec-Windsor corridor (and possibly elsewhere) have to be relaxed and replaced by requirements of vehicle maneuverability.

Specific conclusions arising from cost-efficiency analyses follow.

1. An articulated or double-deck high-capacity bus always produces lower cost of transportation per seat-kilometer vis-à-vis the standard (45-seat) coach on routes on which passenger demand per departure exceeds the capacity of the standard coach.

2. The introduction of any one of the large buses investigated here would lower total costs on all of the six routes (within the Quebec-Windsor corridor) that were included in this study. In general, the higher the capacity of the bus, the lower is the unit cost—provided that seating density is comparable. The 80-seat articulated or double-deck bus is nearly 35 percent more cost-efficient than the standard coach. The 100-seat articulated double-deck bus (with somewhat greater space per passenger) is also nearly 35 percent more cost-efficient than the standard bus.

3. For comparable seating density configurations, the highest reduction in cost is achieved with the use of articulated double-deck bus units. However, only a small number of routes have sufficient travel density for cost-effective application of this option. Also, there could be operational constraints. Consequently, it is doubtful that this type of bus will be accepted by carriers. The choice between the rigid body double-deck bus and the articulated bus would be an operational one because both are equally efficient for the corridor routes studied.

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REFERENCES

1. *Freight and Passenger Forecasts 1985*. TP2957. Strategic Planning, Transport Canada, Ottawa, Sept. 1985.
2. R. Schipizky and Y. Deslauries. Analysis of the Canadian Intercity Bus Passenger Industry. Presented at Annual Conference of Institute of Transportation Engineers, Canada, Ottawa, June 4-6, 1984.
3. *Transport Review, Trends and Selected Issues, 1984*. Research Branch, Canadian Transport Commission, Ottawa-Hull, 1984.
4. *Transportation in a Resource Constrained Future, Intercity Passenger Travel in Canada*. Report 34. Science Council of Canada, Ottawa, Sept. 1982.
5. H. Valentine. *The Intercity Bus in Canada, an Industry at a Turning Point*. Transportation Study Group, Science Council of Canada, Oct. 1983.
6. A. M. Khan. *Canadian Highway Transportation: A Strategic Research and Development Program*. Background Paper. Research and Development Directorate, Transport Canada; A.K. Socio-Technical Consultants, Inc., Ottawa, March 1985.
7. *TDC 1984 Project Directory*. TP1936E. Transportation Development Centre, Transport Canada, Montreal, 1984.
8. M. Nookala. *The Cost-Effectiveness of Intercity Rail and Bus Transportation in the Quebec City–Windsor Corridor*. Master's thesis. Carleton University, Ottawa, Ontario, Canada, 1983.
9. N. D. Lea and Associates. *Feasibility of the Introduction of Larger Capacity Intercity Buses*. Transport Canada, Montreal, April 1979.
10. Hickling Partners, Inc. *Intercity Bus Design: A Route to the Future*. TP4009. Transport Development Centre, Transport Canada, Montreal, Jan. 1983.
11. L. R. Lennox and M. I. Rubinstein. Status of Intercity Surface Transportation Alternatives. Presented at ITE Canada Annual Conference, Ottawa, June 4–6, 1984.
12. B. B. Mayer and G. W. Taylor. The Testing and Development of a High Capacity Coach. Presented at ITE Canada Annual Conference, Ottawa, June 4–6, 1984.
13. *The Potential for High Capacity Buses in Canada*. Transportation Development Centre, Transport Canada, Montreal, 1979.
14. A. M. Khan et al. *Intercity Passenger Transport Energy Efficiency, Data Base and Case Study*. TP2067. Strategic Studies Branch, Transport Canada, Montreal, June 1979.

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Michigan University and College Student Home Location Study

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The home locations of students attending 26 of Michigan's largest 4-year universities and colleges are examined to determine potential weekend intercity bus service. The objectives of the study were to (a) assess the extent of Michigan intercity bus services that accommodate weekend student trips, (b) provide enrollment data for individual schools, (c) develop a process to identify potential special weekend intercity bus service corridors, (d) determine potential service corridors, and (e) create or nurture a cooperative climate between schools and carriers. Five items were developed for each school: student distribution map identifying student home location concentrations; time-distance map indicating driving times between the school and various parts of the state; state trunk line assignment plot portraying simulated student travel patterns; description of existing service accommodating these patterns; and identification of potential service schools and corridors. Six findings evolved. These pertained to schools and routes with strong potential, schools and routes with moderate potential, trip length factors, school–urbanized area relationships, school size threshold regarding weekend service, and need for a user's guide.

Michigan is the home of a myriad of fine public and private universities and colleges attended by more than ½ million students. These schools serve the state's 9 million residents (Figure 1) plus students from other states and many countries. Some of the resident Michigan students and those living in neighboring states and Ontario make trips home, or to other schools, on weekends and holidays *(1)*. Sometimes they make the trip by intercity bus. Often, however, no convenient service is available and students must use other means of travel or not make the trip at all.

OVERVIEW

Reasons for Study

Additional special weekend service is a likely area for successful route expansion because of favorable ridership levels on existing special university and college routes and the transportation benefits to the students involved. The purpose of the Michigan University and College Student Home Location Study was to identify potential corridors for intercity bus service to better accommodate student weekend trips. Five objectives were established to achieve this purpose:

- Assess the extent of intercity bus service in Michigan that accommodates weekend student trips,
- Provide enrollment data aggregated at the traffic analysis zone or local governmental unit level,
- Develop a process to determine potential special weekend intercity bus service corridors,
- Identify potential weekend home travel corridors, and
- Create or nurture a cooperative climate between the university or college community and the intercity bus carriers.

Michigan Department of Transportation, P.O. Box 30050, Lansing, Mich. 48909.

Universities and Colleges in Michigan

Michigan is the home of some seventy 4-year universities and colleges with a total enrollment of more than 300,000. These schools vary in size from a few hundred to more than 40,000 students. Their offerings vary from specialized curricula that serve a relatively small market area to a wide-ranging spectrum that attracts students from all over the world. The 4-year schools are supplemented by another approximately 30 community colleges with a combined enrollment of 255,000 students.

School Selection Criteria

Twenty-six schools were included in the study (Figure 2). These schools represent 4-year institutions with enrollment levels of 1,000 or more that provided the requested data. Initially, information was requested from all 2- and 4-year schools in the state. A preliminary review of the data from these schools indicated that, in general, the student population of all 2- and 4-year schools with fewer than 1,000 students is either primarily commuters or too small for successful intercity bus service.

Twelve schools met the criteria but did not provide the student home residence information requested. Some of the schools chose not to participate because they thought that a majority of their students were commuters and would not benefit from the study. Others were unable to easily provide a distribution of student home locations.

Existing Intercity Bus Service

Michigan's intercity bus service is concentrated in the southern one-half of the Lower Peninsula (Figure 3). Fifteen urbanized areas located wholly or partly in Michigan are served with at least five daily round trips with two exceptions (Niles/South Bend and Port Huron). Three-fourths (74 percent) of all county seats, including all county seats in the southern half of the Lower Peninsula, have daily intercity bus service (Figure 4).

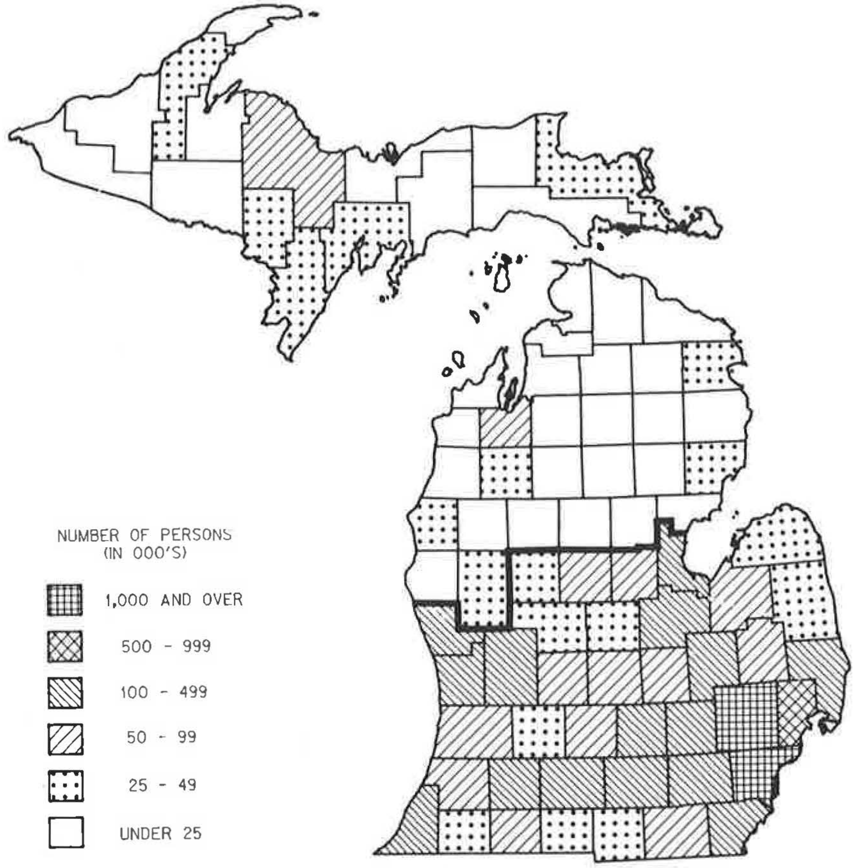

FIGURE 1 1980 population (number of persons).

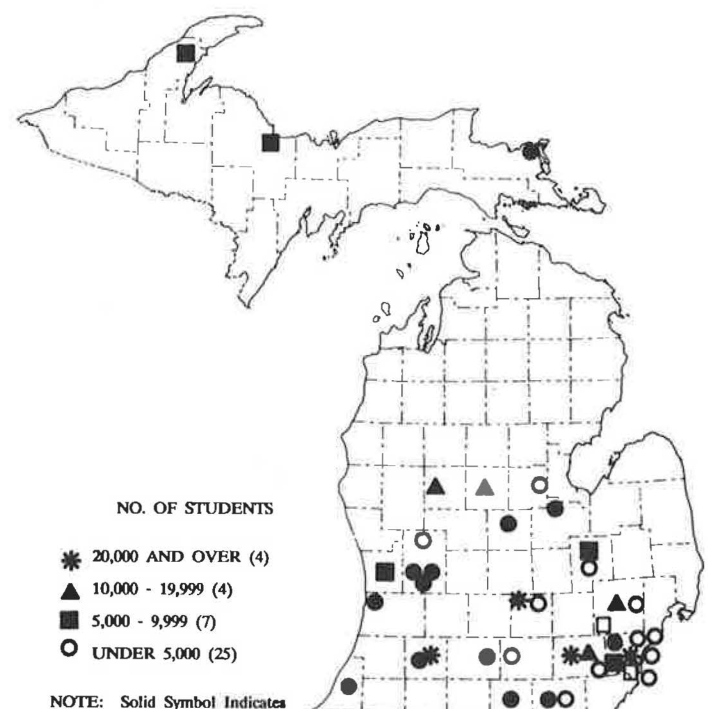

FIGURE 2 Four-year universities and colleges in Michigan with 1,000 or more students, 1984.

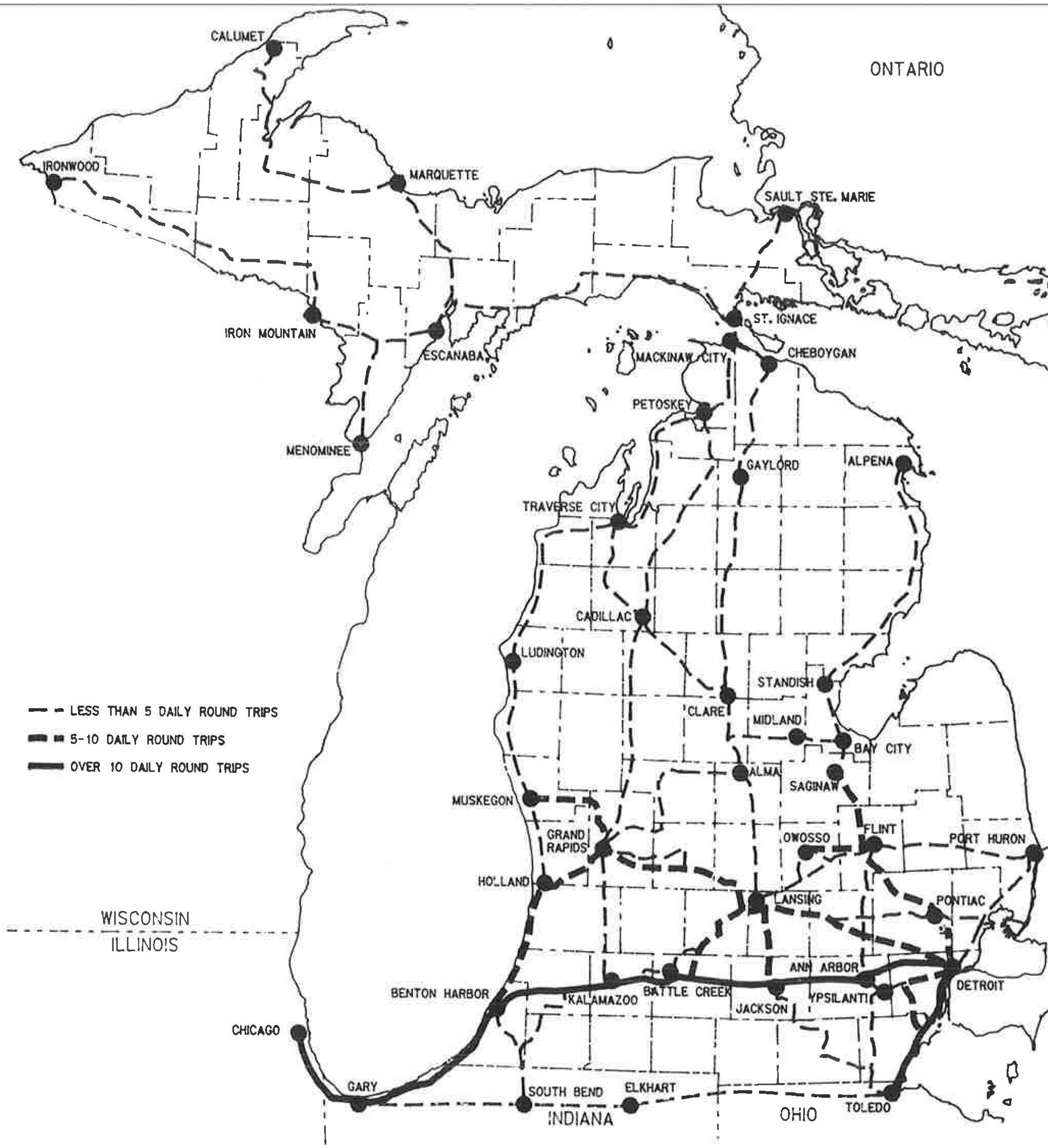

FIGURE 3 Intercity bus system, 1986.

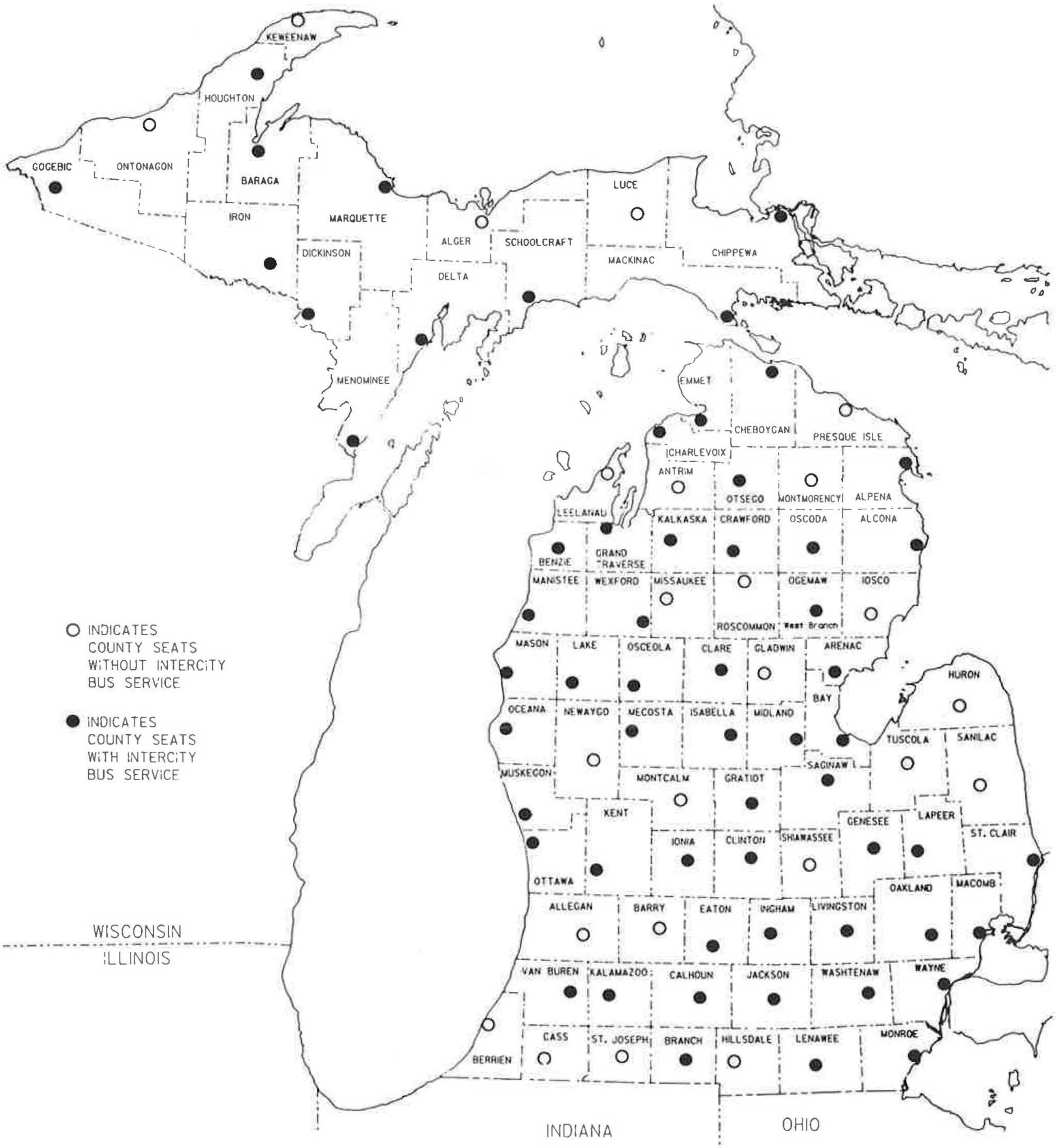

FIGURE 4 Michigan county seats and bus service, 1986.

All but two of the communities in which the 26 surveyed schools are located have at least one daily round trip.

Some existing intercity bus services are tailored to accommodate student weekend travel. These range from daily service with departure and arrival times convenient for weekend student travel, to special weekend schedules, to extra sections on existing routes. Some examples follow.

1. Michigan State University (East Lansing). Special service to Bay City, Flint, Owosso, and Saginaw (one Friday); from Chicago, South Bend, Benton Harbor, Kalamazoo, and Battle Creek (one Sunday); from Big Rapids, Detroit, Grand Rapids, and Reed City (daily service that will stop to discharge passengers only on request); special service to Southfield and Detroit (four Friday); from Lincoln Park, Detroit, Ypsilanti, Ann Arbor (one Sunday); and from Detroit, Royal Oak, Southfield (one Sunday).
2. Michigan Technological University (Houghton). Special Friday and Monday service to Marquette, Escanaba, Green Bay, and Milwaukee (one Friday, one Monday).
3. Northern Michigan University (Marquette). Daily service that stops to discharge passengers only on request from Escanaba, Green Bay, and Milwaukee.
4. Oakland University (Rochester). Daily service that stops to discharge passengers only on request to Mt. Clemens and Utica (one daily), and Ann Arbor, Farmington, and Pontiac (twice daily).
5. University of Michigan (Ann Arbor). Special Friday and Saturday service to Detroit (two Friday, three Sunday).
6. Western Michigan University (Kalamazoo). Special service to Chicago (one Friday, one Sunday), Detroit (one Friday, three Sunday), Flint (one Friday, three Sunday), and Lansing (one Friday, three Sunday).

Potential Service Criteria

Successful intercity bus service was defined as a route expected to regularly carry at least 25 persons. This is assumed to be the minimum number of riders needed to recover the cost of operating a 47-seat intercity bus. For instance, 2.5 percent of the total enrollment of a school with 1,000 students would have to use the special service at any one time to make it successful. This means substantially more than 2.5 percent would have to live in a single corridor to achieve the 25-person ridership level on a given weekend.

A second criterion was that the presence of at least one student home location concentration (SHLC) was necessary to warrant weekend intercity bus service consideration. SHLCs were defined as counties with at least 100 student residents attending the school being considered.

One limitation was placed on these two criteria. No SHLC greater than 3 hr distance from the school was eligible because this was considered the outside time-distance threshold for weekend student travel. This is not to say that no student would travel farther to go home, but it was assumed that not many would do this on a regular basis using intercity bus service.

School Characteristics

Some general characteristics of the schools included in the study follow.

- All are 4-year universities or colleges with fall 1984 enrollments of 1,000 or more students according to the Michigan Department of Education (Table 1).
- Twenty-three (85 percent) of the 26 schools are located in the southern half of Michigan's Lower Peninsula (as defined by an imaginary line drawn from Muskegon to Bay City). This corresponds to the population concentrations in the state; 85 percent of the population also resides in the southern half of the Lower Peninsula according to the 1980 census (Figure 1).
- Fifteen (58 percent) of the 26 schools are located near at least one of the state's 15 urbanized areas (all of which are located in the southern half of the Lower Peninsula). However, the 15 schools are not evenly distributed among the urbanized areas.
- All 11 schools not in urbanized areas are located in county seat communities; 12 of the 15 urbanized-area schools are also located in county seats.
- Slightly more than one-half (58 percent) of the schools are public (state affiliated).
- Most (84 percent) of the schools have convenient access to an Interstate highway. Each school is served by an Interstate or other state trunk line.
- Eighty-eight percent of all students enrolled in Michigan's 4-year institutions during 1984 are included in this study.
- Most of the communities in which the schools are located have at least one regularly scheduled daily intercity bus round trip: two (8 percent) school communities have no service; ten (38 percent) school communities have at least one but fewer than five daily round trips; seven (27 percent) school communities have 5 to 10 daily round trips; and seven (27 percent) school communities have more than 10 daily round trips.

STUDY METHODOLOGY

Carrier Cooperation

The concept of the study was presented at a meeting of the Michigan Intercity Bus Task Force before and again early in the study to obtain carrier input. The universities and colleges to include in the study and the timing and format of the study products were among the items of interest to the carriers. Because of their comments, an early release of data and concomitant analysis for Michigan's six largest universities was made.

Initial Contact

Initially, each 2- and 4-year university and college in Michigan was contacted by letter to the registrar's office. The study was described and each school was requested to provide home residence information by class and zip code for their 1984 fall term student population.

TABLE 1 FALL ENROLLMENT, 1977–1985

University/College	1977	1978	1979	1980	1981	1982	1983	1984	1985	Change 1985-84	Percent Change
20,000 & Over											
Michigan State	47,383	46,567	47,350	47,316	44,887	42,730	41,765	42,193	42,746	553	1.3
U of M, Ann Arbor	35,954	36,577	36,158	37,117	35,677	34,907	34,593	34,467	34,456	-11	0.0
Wayne State	34,389	34,514	34,337	33,408	31,522	29,775	29,639	29,070	28,424	-646	-2.2
Western Michigan	22,496	22,447	22,842	22,641	21,999	20,580	20,296	20,233	20,963	730	3.6
Total	140222	140105	140687	140482	134085	127992	126293	125963	126589	626	0.5
10,000-19,999											
Central Michigan	17,973	17,802	17,779	18,269	17,653	17,132	17,259	16,882	17070	188	1.1
Eastern Michigan	19,104	18,655	18,865	19,323	18,766	18,078	18,880	19,210	20166	956	5.0
Ferris State	9,965	10,208	10,596	11,112	11,261	11,008	10,767	10,540	10909	369	3.5
Oakland University	11,051	11,220	11,729	12,006	11,644	11,721	12,084	11,971	12586	615	5.1
Total	58093	57885	58969	60710	59324	57939	58990	58603	60731	2128	3.6
5,000-9,999											
Grand Valley State	7,469	7,065	7,142	6,984	6,699	6,366	6,710	7,153	7667	514	7.2
Michigan Tech	6,807	7,130	7,690	7,865	7,779	7,640	7,414	6,935	6537	-398	-5.7
Northern Michigan	8,844	8,995	9,452	9,379	9,073	8,377	8,054	7,824	7599	-225	-2.9
U of M, Dearborn	5,480	5,955	6,406	6,291	6,575	6,390	6,399	6,321	6597	276	4.4
U of M, Flint	3,801	3,884	4,122	4,410	4,609	5,025	5,707	5,596	5672	76	1.4
Total	28600	29145	30690	30519	30126	28773	28577	28233	28400	167	0.6
Under 5,000											
Adrian College	912	824	945	1,116	1,242	1,222	1,192	1,220	1139	-81	-6.6
Albion College	1,705	1,784	1,781	1,860	1,876	1,742	1,662	1,569	1571	2	0.1
Alma College	1,170	1,183	1,201	1,198	1,110	1,059	1,004	1,016	1012	-4	0.4
Andrews University	2,837	2,924	2,983	3,018	3,083	2,851	2,878	3,034	3032	-2	-0.1
Aquinas College	1,684	1,918	2,163	2,529	2,753	2,743	2,787	2,831	2724	-107	-3.8
Calvin College	4,075	3,977	3,988	4,058	3,919	3,806	3,938	3,973	4012	39	1.0
Grand Rapids Baptist	1,048	1,137	1,144	1,216	1,132	1,077	1,029	951	910	-41	-4.3
Hillsdale College	1,048	989	1,035	1,035	1,043	1,044	992	1,032	1006	-26	-2.5
Hope College	2,330	2,371	2,355	2,464	2,458	2,530	2,519	2,550	2522	-28	-1.1
Kalamazoo College	1,534	1,444	1,438	1,452	1,367	1,234	1,126	1,106	1115	9	0.8
Lake Superior State	2,261	2,401	2,309	2,501	2,559	2,425	2,820	2,783	2692	-91	-3.3
Mercy College	2,226	2,272	2,281	2,484	2,119	2,106	2,204	2,465	2402	-63	-2.6
Saginaw Valley State	3,529	3,706	3,818	4,285	4,324	4,370	4,612	4,833	4936	103	2.1
Total	26359	26930	27441	29216	28985	28209	28763	29363	29073	-290	-1.0

Source: MDOT, Bureau of Transportation Planning, Passenger Transportation Planning Section, Surface Systems Unit.

Response Screening

Data received from the various schools were reviewed to assure that they were in usable form. This included comparing enrollment figures with those reported by the Michigan Department of Education and assessing the logic of student distribution patterns portrayed by the data. Any inconsistencies or omissions were corrected through discussions with the individual providing the information. In most instances this was the school registrar.

Analysis of the data for 2-year schools during this screening process indicated that

1. Student residence patterns were highly concentrated in the immediate vicinity of the schools and
2. Student residences outside the general area of the school were widely scattered.

These observations were supported by discussions with the registrar's office of these schools. Most students attending 2-year schools generally commute daily to and from school. Screening of the data for 4-year schools with fewer than 1,000 students revealed a similar pattern. Although the 4-year schools were often less commuter oriented, their student home location distribution was generally either localized in a tight cluster, near the school, or thinly scattered. Neither condition would be likely to support special intercity bus service.

This discovery dictated some filtering criteria to determine which schools would most likely benefit from the study. Two criteria were established. Only schools that could meet criteria were included in the final analysis. The two criteria were that

1. The school must have 1,000 or more students enrolled and
2. The school must be a 4-year institution.

These criteria were applied to 1984 enrollment data, provided by the Michigan Department of Education, and classification information from the *1984 Higher Education Directory (2)*. Some schools were excluded by a fine margin; they were just below the 1,000 enrollment mark. On the other hand, two schools that met the enrollment criterion in 1983, but not in 1984, were included (Table 1).

The results of the study tended to support the legitimacy of these two criteria. Schools with lower enrollments, including the two exceptions, that were included tended to be less likely candidates for special intercity bus service unless combined with other schools. Consideration of combined service for the excluded schools, although not part of this study, might be a successful venture for intercity bus companies.

Follow-Up Contacts

After the data were screened and criteria were established, renewed efforts were made to contact those 4-year schools with 1,000 or more students that had not responded to the initial contact. Some schools indicated that retrieval of the information was impossible. In one instance an on-site visit was necessary to manually compile the data. Eventually, data were collected for all but two schools with 5,000 or more enrolled students and for half of those with enrollments between 1,000 and 5,000. Although several schools are excluded, the data collected included nearly 90 percent of all students enrolled in Michigan's 4-year universities and colleges that had a 1984 fall term enrollment of 1,000 or more (Table 2).

No additional efforts were made to obtain information from schools not responding. Information provided by schools that responded but did not meet the criteria was not included in the analysis.

Data Processing

The 26 schools provided a substantial amount of information that needed to be processed in order to analyze patterns and develop conclusions. All student home data had been requested by zip code. A new program was written to match each student's home zip code with one of the 2,300 zones into which Michigan has been divided for analysis purposes. Out-of-state and provincial zip codes and postal codes were matched with special state and provincial codes. Information on students living outside the United States and Canada was excluded. It is unlikely that such students would use intercity bus services for weekend trips home because of the nature or distance of the trip.

Most of the information was provided in a standard format that could be directly entered into the computer (Table 3). Some data needed to be rewritten into a consistent format for accurate entry into the data base. Rewriting was done by hand on standard coding forms. The information was transferred from these sheets and from the printouts provided by the schools into the mainframe computer data base. The entered data were manually checked for accuracy. Selected parts of the final data base were compared with the original data sheets as a secondary check. After the data were entered into the computer, the new "zip-to-zone" program, which entered the 547 and 2,300 zone numbers on each record, was run.

Graphics

Five maps were generated for each school:

1. Student home location distribution in Michigan by county (83 counties).
2. Student home location distribution in Michigan by traffic zone (547 zones).
3. Student home location distribution in the Midwest by county in Michigan and by state for other states. In addition, a state-by-state map of the United States was generated for schools with a nationwide distribution of students.
4. Time-distance (minutes) access in Michigan by traffic zone (547 zones).
5. Simulated student travel patterns in Michigan obtained by assigning trips between home and school to Michigan's trunk line system.

Preliminary Analysis

A preliminary analysis was prepared before the technical report was published. The preliminary report contained an analysis for Michigan's six 4-year universities with enrollments of 15,000 or more. It was distributed to major intercity bus carriers, both regular route and charter, that serve the state in an effort to (a) provide a product for use by the intercity bus companies in time for the fall school season and (b) obtain input from the carriers about the content of the report.

One result of the preliminary analysis was the interest of one intercity bus carrier in establishing new weekend service to three of the six universities included in the preliminary analysis. Difficulty in obtaining student addresses from the schools for direct marketing has delayed provision of service to

TABLE 2 FOUR-YEAR UNIVERSITIES AND COLLEGES IN MICHIGAN, 1984

	No. of Schools			Enrollment (fall 1984)		
Enrollment	Surveyed	Total	Percentage	Surveyed	Total	Percentage
20,000 and more	4	4	100.0	125,963	125,963	100.0
10,500–20,000	4	4	100.0	58,603	58,603	100.0
5,000–10,000	5	7	71.4	33,829	45,778	73.9
1,000–5,000	13	25	52.0	29,363	52,069	56.4
Total	26	40	65.0	247,758	282,413	87.7

SOURCE: Michigan Department of Transportation, Bureau of Transportation Planning, Passenger Transportation Planning Section, Surface Systems Unit.

TABLE 3 SAMPLE DATA FOR STUDENT COUNTS BY ZIP CODE (typical example of how data were provided)

Zip Code	Freshman	Sophomore	Junior	Senior	Graduate	Total
48087	6	12	5	11	4	38
48088	2	11	4	6	12	35
48089	3	3	7	5	0	18
48091	5	5	3	6	1	20
48092	13	4	9	10	5	41
48093	8	18	15	27	9	77
48094	6	2	2	4	0	14
48095	1	2	1	4	1	9
48906	0	5	2	9	13	29
48097	1	2	2	1	0	6

these schools. Another carrier suggested that the data in the state map be presented by county instead of by the 547 zones to make it easier to understand the information portrayed. This suggestion was adopted, and data were presented by county on state maps when possible.

ANALYSIS OF INDIVIDUAL SCHOOLS

Three items were addressed for each school: (a) student distribution patterns, (b) existing service accommodating student distribution patterns, and (c) potential service communities and corridors.

Student Distribution Patterns

Student distribution patterns were described using two different features. These are student home location concentrations (SHLCs) and proximity analysis, which uses the time-distance distribution from the school to the students' homes.

The SHLCs describe where significant concentrations of students reside (Figure 5). A "significant concentration of students" is defined as 100 or more students whose home residences are in the same urbanized area or related county and who attend the same school.

Nonurbanized area–related counties and other states and provinces with more than 100 student residences are noted, but urbanized areas are stressed because of their natural potential for special intercity bus service. They have (a) a greater population, (b) a higher population density, (c) more existing intercity bus service and facilities, and (d) a majority of the students and schools located in or near them.

The proximity analysis included the location of each school, the total enrolled student population for the study period, and

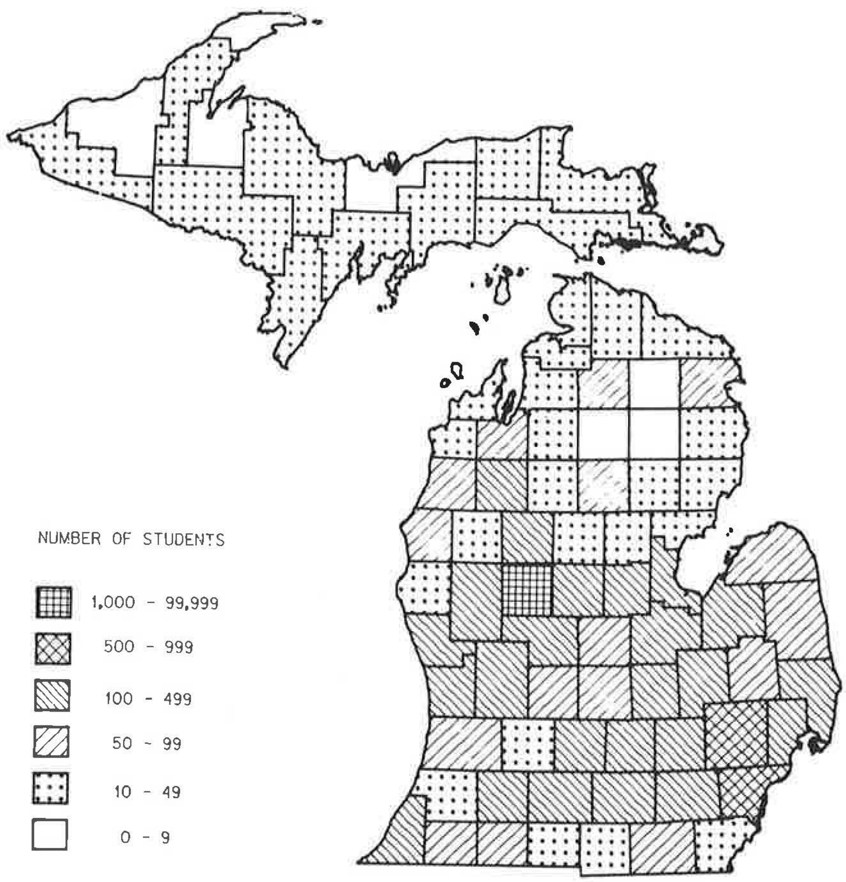

FIGURE 5 Student home locations, Ferris State College.

the percentage of students living within 60, 90, 120, 180, and 181+ min of the school. All students with similar times were grouped together to obtain the total percentage for each distance category.

The percentages in these groups are cumulative except for the 181+-min group. Students reported in the 60-min group are included in the 90-min group; students from both groups are included in the 120-min group; and students in the 60-, 90-, and 120-min groups are included in the 180-min group. The 181+ group contains all students not listed in the previous groups. Care should be taken not to double-count students from previous percentiles when using this information.

Time-distance is a significant determinant for weekend intercity bus service. A very short or long time-distance would be impractical for regular weekend trips home. In this study, a 180-min trip length was used as the maximum time-distance a student could live from school and still have regular weekend travel home as a practical option. This is equivalent to 150 mi assuming an average speed of 50 mph. There are, of course, some students who travel farther, but this study assumed that most students would not make extended trips regularly. Consequently, areas farther than 180 min from the schools are considered to have limited potential for special weekend home service.

Time-distances were delineated for each school using a proximity analysis map (Figure 6) with 547 zones. Analysis of the proximity maps showed that fewer than 5 percent of the students included in this study resided more than 180 min from their school. Seventeen (65 percent) of the 26 schools have fewer than 10 percent of their students living beyond the 180-min distance. All schools except one have fewer than 50 percent of their students in this category (Table 4). This supports the use of a 3-hr time-distance limitation for weekend home travel because a majority of the students included live within this range.

Trunk Line Assignment Plot

A state trunk line assignment plot was used to portray the total number of students traveling to a school from each home location (Figure 7). These plots represent the most optimistic situation because it is unlikely that all students would be traveling at the same time. The routes shown are the minimum time-path trunk line routes from the home location to the school and are cumulative. This graphic provides an opportunity to determine where new intercity bus service might best be established because both direction and student volume are shown.

Existing Service Accommodating Student Distribution Patterns

Existing published bus routes and scheduled time *(3)* that could accommodate student weekend home travel were matched with

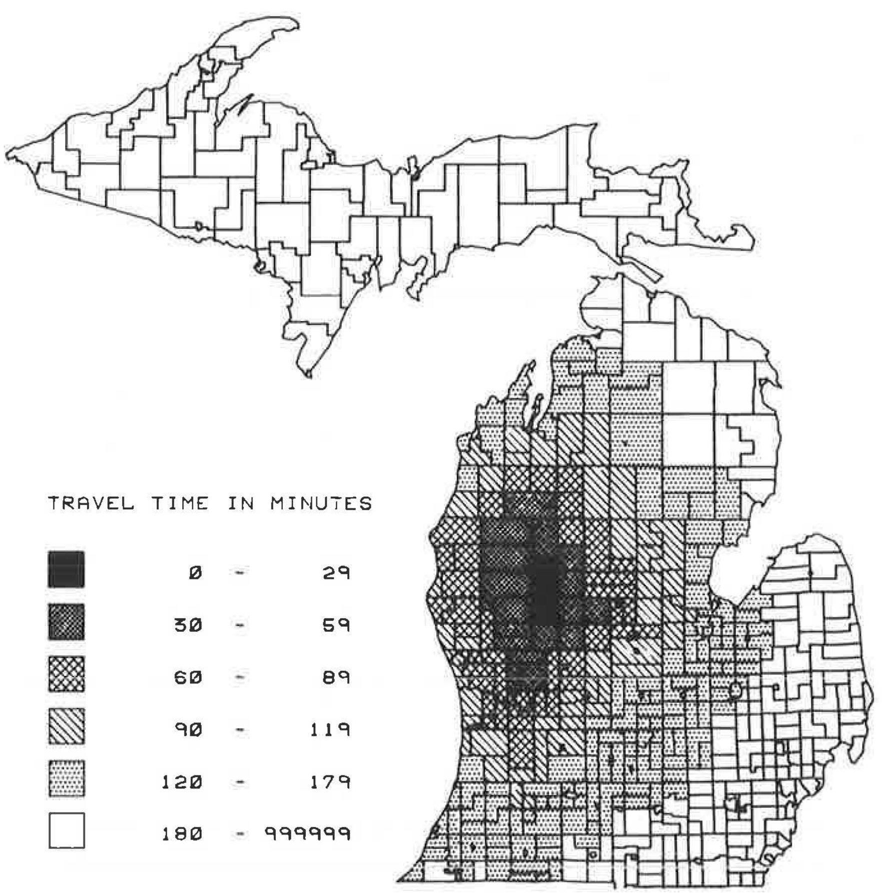

FIGURE 6 Access times to Ferris State College.

TABLE 4 FALL ENROLLMENT BY TIME-DISTANCE, 1984

University or College	Percentage of Students Who Reside at 0–60 min	0–120 min	0–180 min	More Than 180 min
20,000 and more				
Michigan State	32.5	89.6	95.1	4.9
U of M, Ann Arbor	59.3	84.1	94.8	5.2
Wayne State	99.0	99.9	100.0	0.0
Western Michigan	49.4	72.2	92.9	7.1
10,000–19,999				
Central Michigan	21.2	42.7	90.5	9.5
Eastern Michigan	91.2	99.2	99.6	0.4
Ferris State	23.6	43.9	64.1	35.9
Oakland University	97.6	99.9	100.0	0.0
5,000–9,999				
Grand Valley State	80.9	89.0	94.6	5.4
Michigan Tech	21.7	24.2	30.9	69.1
Northern Michigan	56.4	68.0	78.7	21.3
U of M, Dearborn	100.0	100.0	100.0	0.0
U of M, Flint	98.7	100.0	100.0	0.0
1,000–4,999				
Adrian College	26.9	98.1	100.0	0.0
Albion College	17.6	71.4	93.4	6.6
Alma College	31.8	45.5	100.0	0.0
Andrews University	95.5	97.7	97.7	2.3
Aquinas College	82.1	83.6	89.6	10.4
Calvin College	74.9	79.4	82.5	17.5
Grand Rapids Baptist	79.5	81.8	86.4	13.6
Hillsdale College	21.6	23.5	94.1	5.9
Hope College	61.8	71.5	76.4	23.6
Kalamazoo College	32.7	44.9	84.7	15.3
Lake Superior State	41.0	51.7	63.5	36.5
Mercy College	96.0	98.5	100.0	0.0
Saginaw Valley State	90.0	95.0	100.0	0.0

SOURCE: MDOT, Bureau of Transportation Planning, Passenger Transportation Planning Section, Surface Systems Unit.

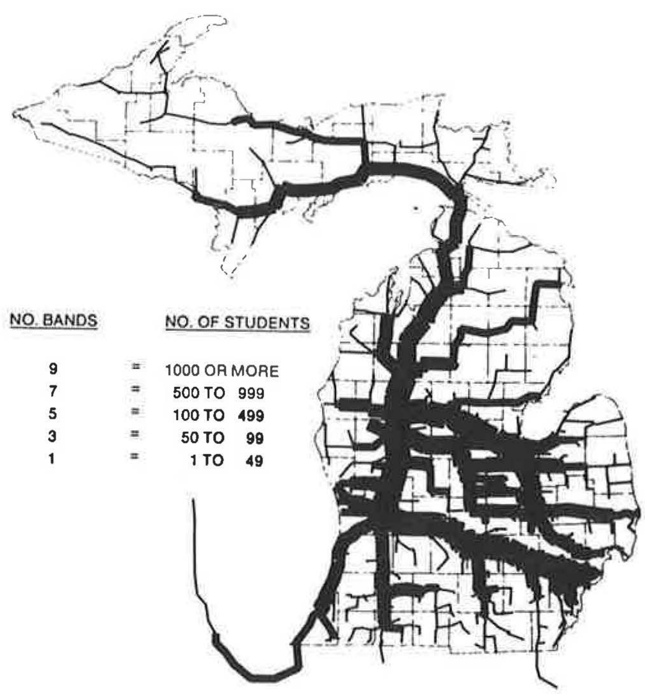

FIGURE 7 Simulated student travel patterns for Ferris State College.

the SHLC and trunkline assignment patterns. These included existing services requiring (a) no alteration in routing or departure times, (b) some alteration in routing or departure times, and (c) supplemental departures to augment the existing schedule.

Potential Service Schools and Corridors

Possible student home travel patterns were identified from the proximity analysis and SHLC. There were instances in which no existing regular or special weekend service was meeting the needs of student travel home. Areas with a high SHLC but with limited, oddly scheduled, or no service to the school were identified.

Analysis of Selected Schools

Each school was analyzed using the tools described previously to identify student distribution patterns, existing service accommodating these student distribution patterns, and potential service communities and corridors for new service. For example, a set of statements (Figure 8) was developed for Ferris State College based on student home locations, access times, and simulated student travel patterns portrayed in Figures 5, 6,

FERRIS STATE COLLEGE

Student Distribution Patterns

1. Approximately 24% of the 10,540 students attending Ferris State College reside within 60 minutes of the campus in Big Rapids, 34% within 90 minutes, 44% within 120 minutes, and 64% within 180 minutes.

2. Student Home Location Concentrations (SHLC) are found in 14 of the 15 urbanized areas in the State of Michigan; Ann Arbor, Bay City, Battle Creek, Benton Harbor/St. Joseph, the Detroit Metropolitan Area, Flint, Grand Rapids, Jackson, Kalamazoo, Lansing, Muskegon, Niles/South Bend, Port Huron, and Saginaw.

Existing Service Accommodating Student Distribution Patterns

3. Existing service connects Big Rapids to Grand Rapids, Lansing, Jackson, and Adrian via the US-131/I-96/US-127 corridor. Connections can be made at Grand Rapids to Benton Harbor/St. Joseph or Muskegon and from Lansing to Detroit via I-96.

Potential Service Communities and Corridors

4. Because of the wide student distribution pattern, there is a large potential for additional special weekend routes serving Ferris State College. Potential exists from Big Rapids via Grand Rapids to Kalamazoo and Battle Creek because of long layover periods in Grand Rapids on the regularly scheduled routes. This service could be coordinated with the other universities and colleges in Grand Rapids and Kalamazoo.

5. Potential exists for a special service from Big Rapids to Midland, Bay City, Saginaw, Flint, and possibly to Port Huron.

6. Consideration should be given to providing a direct route from Grand Rapids to Lansing to Jackson to Ann Arbor and Detroit. The current route heads south from Jackson to Toledo without stopping in Ann Arbor or Detroit. Riders headed for these destinations must transfer in Grand Rapids.

FIGURE 8 Statements describing Ferris State College.

and 7, respectively. The statements indicate that the college has a wide distribution pattern and that several routes have potential. One is an express route from Big Rapids to Kalamazoo and Battle Creek via Grand Rapids. Currently, layovers in Grand Rapids make travel to Kalamazoo and Battle Creek tedious. This route could be scheduled to connect with the bus arriving in Grand Rapids from Central Michigan providing service connections for both schools. A second is service between Big Rapids and Midland, Bay City, Saginaw, Flint, and possibly Port Huron. A third is a direct route from Big Rapids to the Detroit metropolitan area. Current routes head south in Jackson to Toledo, omitting Ann Arbor, Ypsilanti, and Detroit.

FINDINGS

The data obtained from the 26 universities and colleges led to several findings. These include strong and moderate potential routes, trip-length factors, school–urbanized area relationships, school size threshold, and need for a user's guide.

1. Schools and routes with strong potential. Routes with no weekend intercity bus service convenient to student travel but with strong potential were identified for four schools (Adrian College, Central Michigan University, Ferris State College, and Hillsdale College). These routes connect the schools with SHLCs of 500 or more students. These schools and their associated routes are shown in Figure 9.

2. Schools and routes with moderate potential. Routes with moderate potential were determined for 12 schools and one combination of schools. These routes connect the schools with SHLCs of 100 to 499 students where no convenient weekend intercity bus service is available. Schools in the moderate category are generally candidates for routes that serve more than one location. These schools and their related routes are shown in Figure 10.

The remaining 10 schools have limited potential for new or additional special weekend service for a variety of reasons. These include (a) a school was rated as having sufficient existing service to meet student weekend home travel needs, (b) the student distribution pattern was extremely concentrated (fewer than 100 students residing in an area), or (c) there was an excessive time-distance (more than 180 min or 150 mi) between the school and the SHLC.

3. Trip-length factors. The home-school trip length of university and college students is affected by a number of school characteristics. Some of these surfaced in this study.

- Distance from urbanized areas. The Detroit urbanized area is a stronger influence than the others. Nineteen of the 26

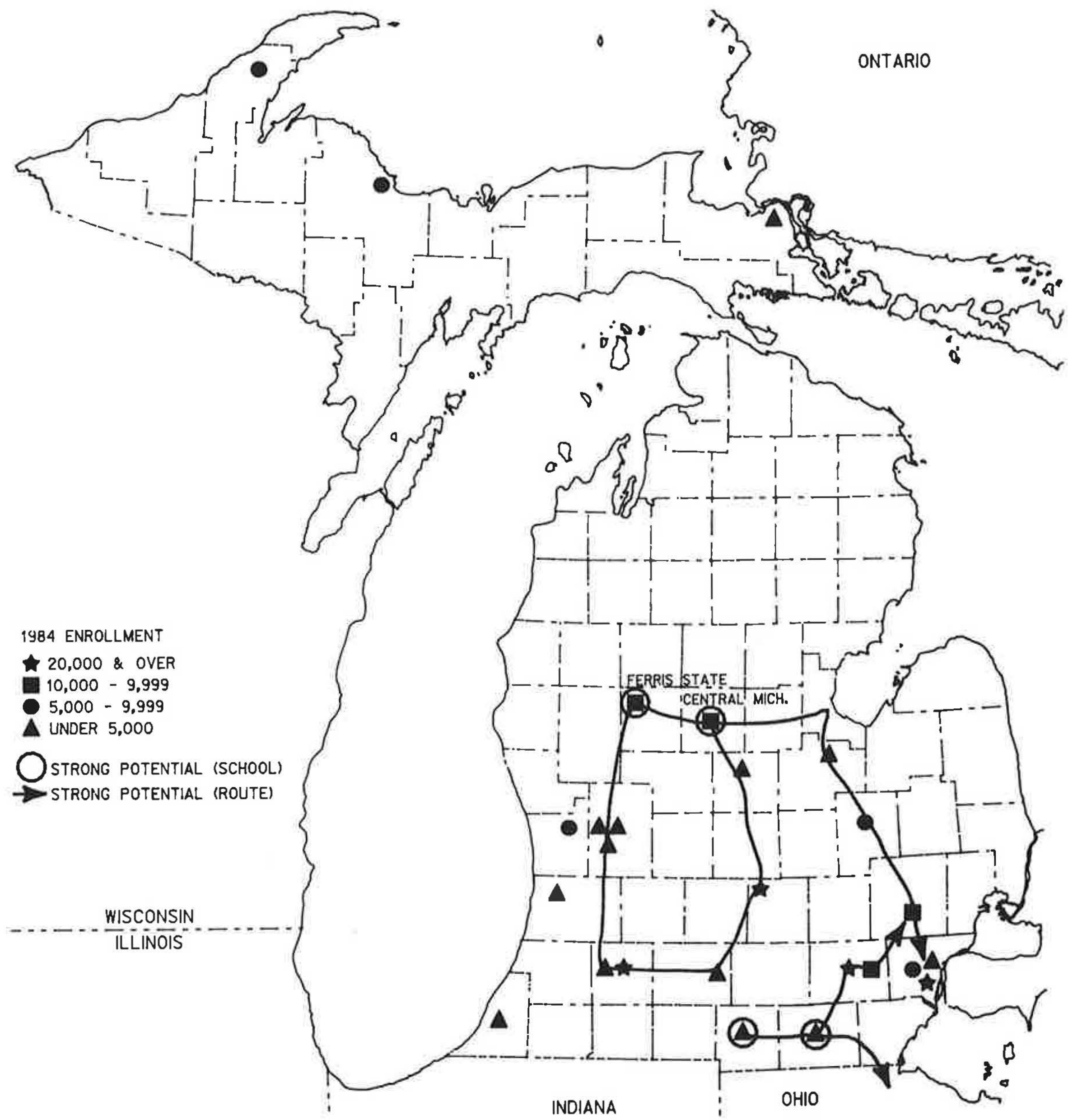

FIGURE 9 Routes with strong service potential.

schools have an SHLC in the Detroit area. In general, a sizable segment of a school's enrollment will come from urbanized areas regardless of how far the school is from these areas.

- Religious affiliation. These schools tend to draw from greater distances than similar-sized public schools. Examples are Aquinas, Calvin, Grand Rapids Baptist, and Hope Colleges (Table 4).
- Reliance on branch campuses. Schools with branch campuses have shorter trip lengths than schools of similar size without branch campuses. The branch schools themselves have a tight distribution of their student population, usually less than 60 min trip length from the school. One example of this is the University of Michigan with branch schools in Dearborn and Flint (Table 4).
- Total enrollment. The largest schools tend to have a greater dispersal of their students' home locations than smaller schools. This means a longer average trip length. Additional factors probably affect trip length but were not identified in this study. These include such items as curriculum and faculty reputation.

4. Relationships between schools and urbanized areas. There are 118 different combinations in which the 26 schools have SHLCs in the 15 urbanized areas. Of these, 7 of 10 have existing intercity bus service that meets student weekend travel needs. More than 90 percent of the 500 or more student concentrations and nearly 60 percent of the 100 to 499 concentrations are served (Figure 11). The 3 of 10 without suitable intercity bus service offer the best opportunities for additional weekend service.

5. School size threshold for weekend service. Schools with an enrollment of 10,000 or more generally have a high number of SHLCs, usually 10 or more. These concentrations are

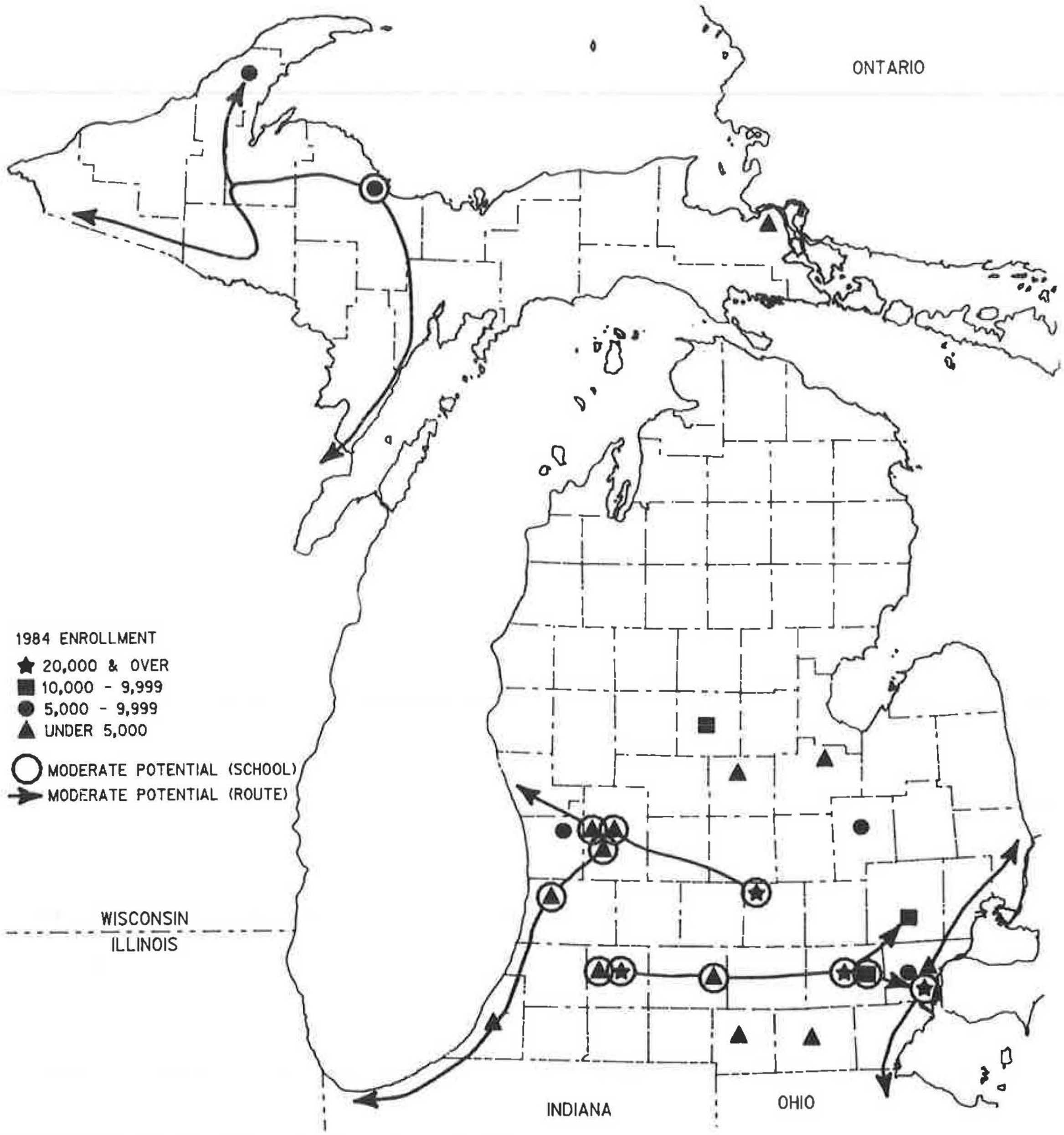

FIGURE 10 Routes with moderate service potential

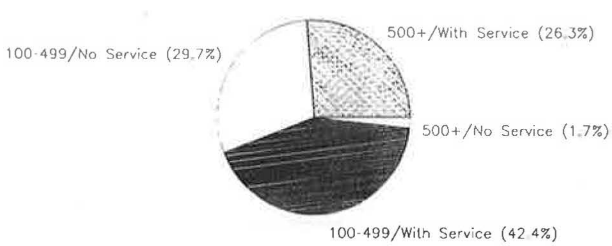

FIGURE 11 Linkage of schools and urbanized areas (student concentration/service).

well served by intercity bus service when the school is located in an urganized area but not particularly well served when located at a distance from an urganized area. Schools with enrollments of from 5,000 to 9,999 usually have five or more SHLCs. Schools in the 1,000 to 4,999 range have one or two concentrations and usually have to be combined to justify home-school weekend intercity bus service. Schools with enrollment under 1,000 will rarely justify service unless they can be conveniently served along a route for which service is otherwise justified. The thresholds for five enrollment groups are given in Table 5.

6. Need for user's guide. During the study it became apparent that a user's guide, describing how to use the data and the tools developed in the study, would be helpful. Consequently, a user's guide was developed. Written in nontechnical language, it provides a suggested methodology for using the data and study findings to establish new or improved service to Michigan university and college students.

TABLE 5 SERVICE POTENTIAL BASED ON SCHOOL ENROLLMENT CATEGORIES (Michigan universities and colleges)

	Service Potential		
Enrollment	Strong	Moderate	Limited
20,000 or more	X	X	X
10,000–19,999	X	X	X
5,000–9,999		X	X
1,000–4,000			X
Fewer than 1,000			

SOURCE: MDOT, Bureau of Transportation Planning, Passenger Transportation Planning Section, Surface Systems Unit.

LIMITATIONS

Some of the limitations of this study, for both the data and the results follow.

- The study uses 1984 enrollment data. Student distribution patterns change. No attempt has been made to determine an average student residence pattern over an extended period of time.
- Some schools that met criteria for inclusion in the study did not furnish data. This could have excluded significant potential routes from consideration.
- The maps and data used to determine potential routes are based not on the actual desires of students of each school for weekend transportation home but on the number of students residing in an area and generalized student ridership figures collected in previous intercity bus surveys. The actual demand by students at each school may be different.
- The study does not consider student needs. There is no way of knowing from the data used in this report how many students at each of the schools have an automobile or alternate arrangement for transportation home on weekends, which would eliminate these students from consideration for intercity bus trips.
- Intercity bus companies may find it difficult to promote new services through direct, targeted mailings. Most universities and colleges in Michigan are sensitive about releasing student residence information to for-profit businesses. Without this information, intercity bus companies may be required to find alternative marketing methods, which may be less successful and more expensive.

FOLLOW-UP ACTIVITIES AND FUTURE DIRECTIONS

The technical report was transmitted via meetings and mailings to (a) 83 carriers providing, or with the potential of providing, weekend intercity bus service to Michigan's university students; (b) 26 Michigan universities and colleges participating in the study; (c) 14 Michigan planning and development regions plus separate metropolitan planning organizations and comprehensive, coordinated, cooperative (3-C) planning areas; (d) about one-third of the nation's state departments of transportation; (e) Transportation Research Board annual meeting attendees; and (f) other interested parties.

Several inquiries have been received from potential service providers. These were requests by intercity bus and limousine service providers for more detailed home location data on specific potential routes. The general reaction among carriers is that this is the type of activity that state DOTs should be undertaking. Although no new services can be traced directly to the work presented in the technical report, two new services accommodating weekend student travel were initiated in early 1987. These were between two of Michigan's largest universities and communities in southeast Michigan.

Future directions include at least three items. One is to transmit a follow-up letter to carriers to determine whether, and how, the report has been useful. A second is to obtain student car availability data in any future undertaking of this kind. This would include determining the number of students with on-campus automobiles and assessing school policies regarding on-campus automobile possession and use by students. The third is to update the data base every 4 years if the usefulness of the study results so warrants.

REFERENCES

1. *Michigan Intercity Bus Study: A Comparison of 1985 and 1977 User and Ticket Surveys.* Surface Systems Unit, Passenger Transportation Planning Section, Bureau of Transportation Planning, Michigan Department of Transportation, Lansing, Dec. 1985.
2. *1984 Higher Education Directory.* Higher Education Publications, Inc., Washington, D.C., 1984.
3. *Russell's Official National Motor Coach Guides.* Russell's Guides, Inc., Cedar Rapids, Iowa, March 1986, Part I.

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An Assessment of the User Benefits of Intercity Bus Service

ERIC HANSEN AND EDWARD BEIMBORN

Benefits of intercity bus service are examined, and methods to estimate them are proposed. Benefits occur to both users and nonusers. User benefits include travel cost savings, improved convenience, and reduced travel time as well as benefits to freight users. Nonuser benefits include option value, merit value, and perception of community accessibility. Benefits to users are estimated by comparing the disutility of travel by intercity bus to travel by automobile or some other intercity bus route. A model is developed to calculate a benefits index of a given bus service as a function of the characteristics of automobile and bus travel, user characteristics, and modal preference parameters. Sensitivity analyses were conducted and indicate that the level of benefits is highly sensitive to the isolation of a route and to the cost of automobile travel. Other factors such as value of time, out-of-vehicle time weight, out-of-vehicle time, and percentage of captive users have a more moderate effect.

In the aftermath of federal deregulation of the intercity bus industry, considerable attention has focused on the actual or potential loss of intercity bus service in small communities and rural areas across the nation. Much of the discussion has centered on the impact of deregulation in general *(1, 2)*, on small communities *(3)*, and on approaches for addressing the loss of bus service such as subsidies or alternative rural transportation systems, or both *(4)*. In the recent literature, the question of whether intercity bus service should be subsidized has been generally addressed by examining the cost structure faced by the carrier for any particular route and showing that costs exceed revenues *(5)* or by assessing the "need" for service *(4)*. Although theory indicates that a subsidy is warranted only if social benefits exceed social costs, no one has attempted to evaluate rigorously the "benefits" of intercity bus service. To accurately assess the appropriateness of a subsidy for intercity bus service, however, the benefits of intercity bus service must be estimated.

In this paper a procedure for estimating the benefits of intercity bus service is documented. The paper includes a conceptual framework, a model for estimating passenger benefits of intercity bus service, and an application of the model to case studies of two intercity bus routes in Wisconsin, which are currently receiving federal Section 18 subsidies. The paper ends with a discussion of the policy implications of the research and conclusions. For the purposes of this paper, intercity bus service is defined as regularly scheduled line-haul service available to the fare-paying public traveling between two or more cities. Further details on the project are available in a report to the Wisconsin Department of Transportation *(6)*.

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CONCEPTUAL FRAMEWORK

The literature on cost-benefit analysis provides a general outline for assessing the benefits of transportation projects [e.g., Wohl and Martin *(7)*, Mohring and Hartwitz *(8)*, and Manheim *(9)*]. The benefits of transportation projects are commonly identified in terms of user and nonuser benefits.

User Benefits

User benefits of a transportation service are customarily measured by the user's willingness to pay for the service as reflected by the area under the demand curve. To derive the "net" user benefits of a transportation service or project, however, the difference in willingness to pay between this service or project and the next best alternative must be derived.

At present, the consumer-surplus and user-cost measures are the most commonly used ways to evaluate user benefits in transportation projects *(9)*. In this paper the consumer-surplus view has been adopted because, conceptually, it adheres most closely to economic theory and because it is more appropriate when the demand curve is inelastic as it is in the case of demand for intercity bus by most users.

User benefits accrue to passengers and freight shippers and receivers. Essentially, users of intercity bus services benefit by the amount that the intercity bus is cheaper, more convenient, faster, and so on than the next best available mode. User benefits are characterized in terms of differences in user costs (disutility savings) between the bus and alternative modes. Conceptually, passenger benefit of an intercity bus trip between two places is simply the difference between the disutilities of the next best alternative (automobile or another bus route) and the intercity bus.

The question of freight benefits can be handled in a similar manner. Benefits accrue from freight service because intercity bus service has some advantages over alternative freight carriers. In general, intercity bus is used for freight purposes because of a time advantage or because of more liberal commodity or weight limits. In Wisconsin small package service appears to be dominated by other carriers (chiefly United Parcel Service) and intercity bus appears to be used only for certain commodities that cannot be accommodated by the other carriers. Intercity bus is used primarily for delivery of fresh flowers, blood, large automobile parts, and certain documents.

Freight benefits can be calculated using a procedure analogous to that used for passenger benefits.

Nonuser Benefits

In addition to direct benefits to users of bus services, it is often argued that nonusers benefit from public bus service *(10)*. Nonuser benefits include option value, merit value, and perception of community accessibility. Option value refers to goods or services that are used as a backup for another good or service or that will be valuable in the future. For example, the intercity bus has option value to those who would use it if their car broke down. Option value benefits can be measured using the disutility savings framework introduced previously. The main difference is that the probability that nonusers will have to resort to the intercity bus must be factored in *(6)*. Urban public transit and intercity bus service also are considered to have merit value in that many individuals (users and nonusers) would be willing to pay something to assure that these services are available to the public. A third nonuser benefit relates to positive externalities associated with intercity bus service. it has been suggested that communities "perceive" an accessibility benefit because intercity bus service may be the only public link for small communities to other communities *(11)*. However, the magnitude of this benefit, real or perceived, is difficult to gauge. On the one hand, it entails assessing the impact of intercity bus service on business productivity (and on the number of businesses that moved into or did not leave the community) and on job accessibility as well as other real impacts *(12)*. On the other hand, the perceived benefit of community accessibility in general must be assessed. The conclusions of two studies suggest that these external effects of intercity bus service on small communities are negligible *(3, 11)*.

MODELS FOR ESTIMATION OF USER BENEFITS

To compare the user benefits of intercity bus service, a model was developed to allow the characteristics of alternative modes of transportation to be compared on a similar basis. The model is based on the concept of travel disutility. The disutility of a trip is a combination of its time, cost, and inconvenience. For this project disutilities were calculated as follows:

$$DU_{ijm} = IV_{ijm} + C_1{*}OV_{ijm} + CT_{ijm}/C_2 + C_{3m}$$

where

D_{ijm} = disutility of a trip between town i and town j using mode m (measured in minutes);
IV_{ijm} = in-vehicle time using mode m between town i and town j;
OV_{ijm} = out-of-vehicle time between town i and town j using mode m;
CT_{ijm} = cost of travel between towns i and j using mode m;
C_1 = out-of-vehicle time multiplier used to represent the inconvenience of waiting and so forth; 1 min of OV time = C_1 min of IV time;
C_2 = value of time in dollars/minute; and
C_{3m} = mode bias factor that represents negative aspects associated with travel using mode m, such as discomfort or inconvenience of schedule, in units of minutes.

This equation is similar to that which is used in logit mode choice models in urban travel demand analysis.

In-vehicle time is the length of the trip divided by speed. Out-of-vehicle time is a fixed amount (different by mode) that represents the time it takes to wait for and board a vehicle. The cost of the trip is either the bus fare for a bus trip or the product of the trip length and a given cost per mile for an automobile trip. The benefits of a mode can then be represented by the difference between its disutility and the disutility of the next best choice. For instance, given the choice of bus or automobile for traveling to another city, the benefits of the bus would be the net savings it provides over automobile in terms of disutility.

For this analysis intercity bus transportation was compared only with automobile and other intercity bus services. Other possible alternatives (i.e., air and rail) were not considered in the framework because the focus was primarily on small, rural Wisconsin towns that usually do not have access to air or rail transportation for intercity trips within the state.

Extensive sensitivity analyses were conducted to determine the effects of various parameters on overall results. The parameters that varied were out-of-vehicle time multiplier, value of time, mode bias factor, length of trip, access distance, relative speed (bus versus automobile), relative cost (bus versus automobile), and degree of captive ridership.

GENERAL SCENARIO

To examine the relative benefits of intercity bus travel and automobile travel, a general scenario was established. The scenario assumes a direct intercity bus route was in existence between town i and town j (Figure 1) and has been discontinued. Individuals wishing to travel from town i to town j now have two choices: to travel directly by automobile to their destination (direct automobile trip) or to travel to the nearest bus station in another town *(x)* and then take an alternative intercity bus to town j. When travelers reach the terminal in town j they complete the trip to their destination by local travel. This second type of trip is referred to as an auto-bus-auto (ABA) trip.

The disutility of bus trips needs to be modified to include the access and egress portions of the trips, calculated as follows:

Direct bus service between i and j

$$\text{DUB} = A_{oi} + B_{ij} + E_{jd}$$

Bus service between i and x and j, x, and j

$$ABA = A_{ox} + B_{xj} + E_{jd}$$

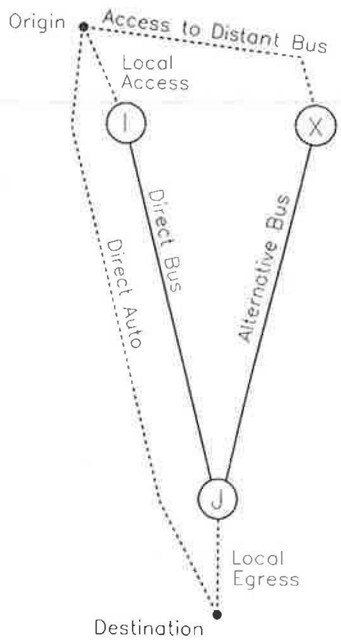

FIGURE 1 General case study.

where

DUB = disutility of a direct bus trip between an origin in city i and a destination in city j,
ABA = disutility of an ABA trip using an intermediate terminal in town x,
A_{oi} = access disutility between origin and a terminal in town i,
A_{ox} = access disutility between origin and a terminal in town x,
B_{ij} = bus service disutility between terminals, and
E_{ij} = egress disutility between terminal in destination city and final destination.

The calculation of automobile disutility is similar in that it also includes local access components in the origin and destination cities. The all-automobile trip has three components of in-vehicle time (for local driving at the origin city, for city to city travel, and for local driving in the destination city) and single out-of-vehicle time, cost, and mode bias coefficients. The disutility of an automobile trip is as follows:

$$ADU = (IV_{oi} + IV_{ij} + IV_{jd}) + (C_1 * OV_{oi}) + (CT_{od}/C_2) + C_3$$

The disutility of an automobile trip is further modified to account for captive users. If a person is a captive user (i.e., unable to use an automobile), it is assumed that the disutility of the automobile portion of the trip would double to account for the disutility of the person who drives to the destination or to the terminal. That is, it is assumed that the traveler would have to compensate a driver by an amount equal to the disutility the driver incurs to make the trip. The disutility of the driver is double because only one-way trips from town i to town j (and not the return trip) are considered.

The disutility of an automobile trip is then its disutility as given previously plus the disutility multiplied by the percentage of captive users to represent these second trips. Thus, because the cost of travel is still paid only once for a vehicle, this is subtracted from the total. The disutility of an automobile trip is then

$$DUA = ADU_{ij} + PC * ADU_{ij} - PC * CT_{od}/C_2$$

where

PC = portion of users who cannot use an automobile for the trip,
AU_{ij} = disutility of the automobile trip between town i and town j, and
CT_{od} = amount of pocket cost of the trip by automobile between the origin and the destination.

It should be noted that DUB and ABA are modified for captive users in a similar way for the access and egress portions of the trip. That is, the disutility of the access and egress portions of the trip is increased to take captive trips into account.

Disutilities are calculated for an all-automobile trip and an ABA trip and compared with the disutility of the original bus trip to determine the disutility savings of the intercity bus service. The savings in disutility (DUS) for an intercity bus trip is then

$$DUS = \text{Min} \begin{cases} DUA - DUB \\ ABA - DUB \end{cases}$$

The disutility savings have to be greater than zero for there to be any direct benefit of intercity travel.

Finally, the disutility savings is calculated for all stations along a bus route, multiplied by a population weight, and divided by the value of time to create the benefit index for a particular transit route:

$$BI = \Sigma\ (DUS_k * PW_k) * C_2$$

where

BI = benefits index;
DUS_k = disutility savings of intercity bus at town k in minutes;
C_2 = value of time in cents per minute; and
PW_k = population weight for station k; this is an indicator of the activity of station k; ideally it is the number of boardings, but could also be given as follows

$$PW_k = (T * P_k)/\Sigma\ P_k$$

with

T = annual trips on the route and
P_k = population of town k.

This equation yields a number that represents the dollar equivalent of the disutility savings for all users along an intercity bus route. It is referred to as a benefit index rather than simply as the benefits of a service because it does not include nonuser or freight benefits. These should be separately recognized when benefits of a service are being analyzed.

APPLICATION

Two intercity transit routes in Wisconsin were examined to demonstrate the use of the model as a means of calculating the relative benefits of different intercity bus routes. The cases used were bus service between Green Bay and Milwaukee via Plymouth, Wisconsin (Green Bay–Milwaukee) and service between Ashland and Abbotsford, Wisconsin. These services are shown in Figures 2–4. Each route is served by one bus a day in each direction. The Milwaukee–Green Bay route has alternative service available relatively close by (Figure 3) and is located in a populous area of the state. The Ashland-Abbotsford service is isolated from other services and located in a sparsely populated part of the state.

A spreadsheet program was developed to calculate the benefits index for these two routes under a variety of conditions. The purpose of this analysis was to test the model and to determine its sensitivity to the various assumptions used. Furthermore, it was used to demonstrate how the model could be used to assess the merits of a particular service for public assistance. A base case was developed and then varied in a sensitivity analysis. The parameters for the base case are given in Table 1. Initially it was assumed that 50 percent of the users had no automobile available for the trip and that annual ridership was 1,000 users in each direction.

TABLE 1 PARAMETERS FOR BASE CONDITIONS

Parameter	Value
Automobile	
Cost/mi	25.00 cents/mi
Rural mph	50.00 mph
City mph	25.00 mph
OV time	5.00 min
Bus	
Cost/mi	14.04 cents/mi
Rural mph	45.00 mph
OV time	5.00 min
Captive ridership	50.00%
Disutility coefficient	
C_1	3.00 min/min
C_2	8.33 cents/min
C_3	
Bus	20.00 min
Automobile	0.00 min
Distance	
Access	1.00 mi
Egress	5.00 mi
Route	60.00 mi
Nearest bus	20.00 mi

Using these values, the benefits index for the Green Bay–Milwaukee route is $3,727 or $1.86 per trip and $7,453 or $3.73 per trip for the Ashland-Abbotsford route. There is a difference between the two routes primarily because the Ashland-Abbotsford route is more isolated from other service (an average of 35.6 mi) than is the Green Bay–Milwaukee route

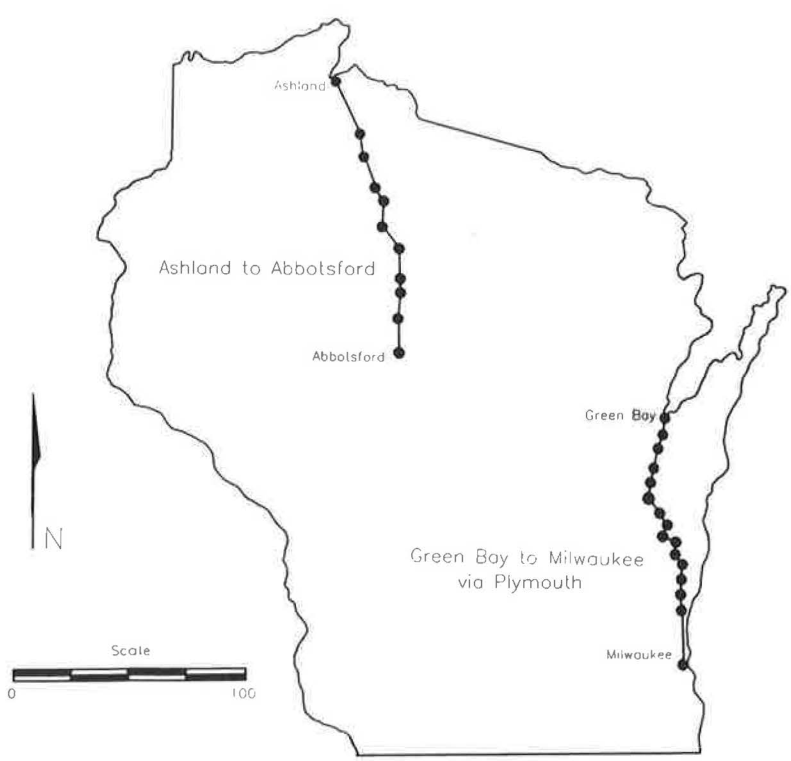

FIGURE 2 General location of test routes.

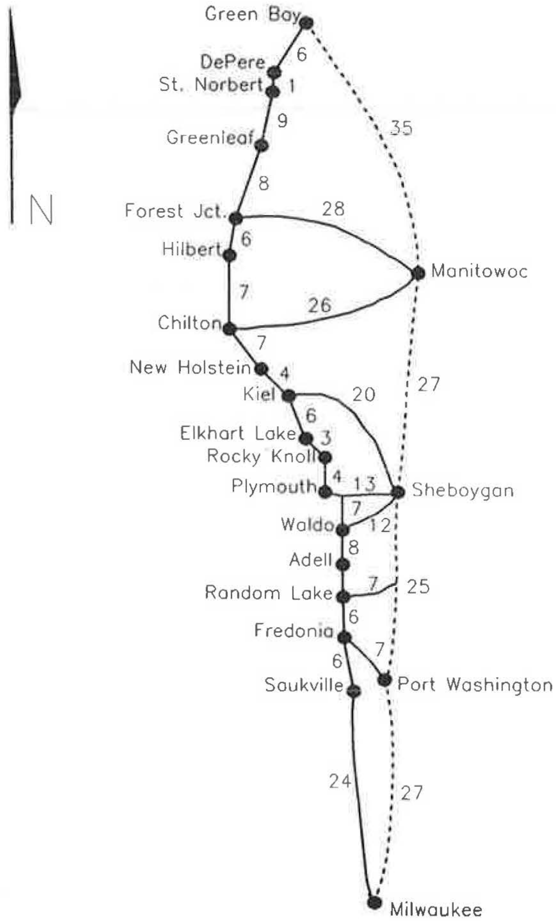

FIGURE 3 Green Bay–Milwaukee route via Plymouth (numbers are distances in miles).

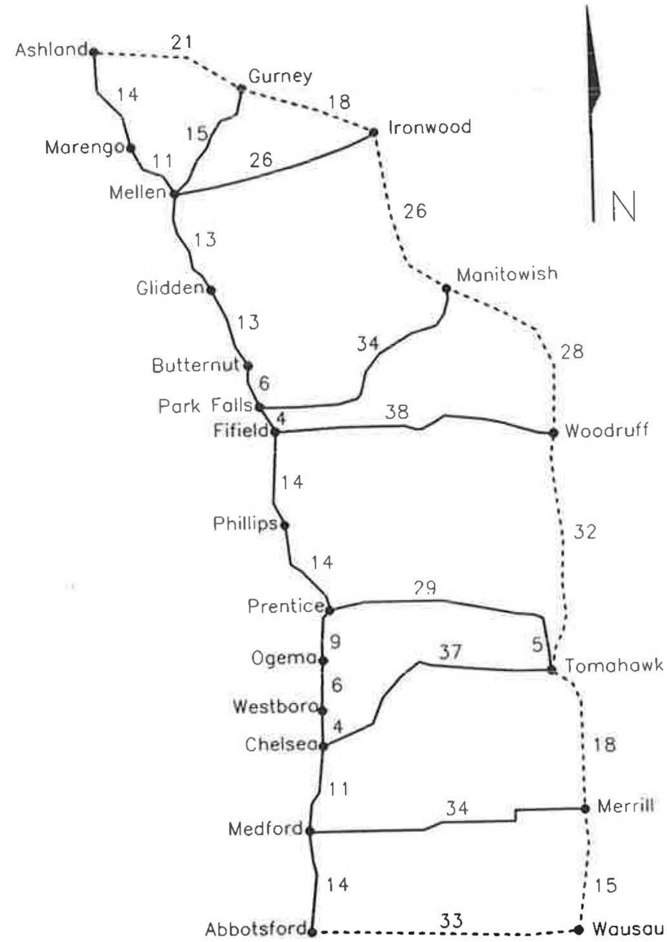

FIGURE 4 Ashland-Abbotsford route (numbers are distances in miles).

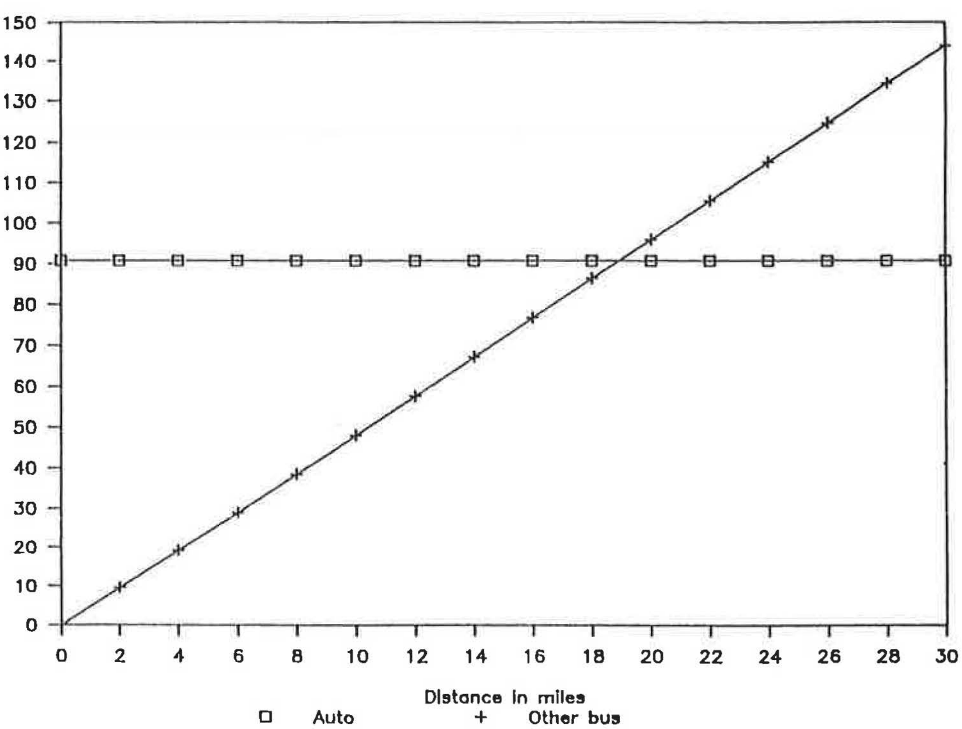

FIGURE 5 Vary distance to nearest alternate bus.

(an average of 15.4 mi). This leads to a larger gap between disutilities of the modes and hence a larger benefits index. This effect can be seen in Figure 5, which shows the effect of the distance to the nearest bus on the disutility calculation for a given station. A 100-mi station-to-station trip is assumed with alternative bus service at a varying distance away. Here the alternative bus is the next best choice for distances of up to about 22 mi. Beyond that point a direct automobile trip is preferred. If the alternative station is remote, the size of the benefits index is large because it depends on automobile travel rather than bus service.

These results imply that the importance of a service depends not only on the magnitude of the ridership but also on the relative isolation of the route. Those routes that are the only service for a large but lightly populated area would tend to have a larger benefits index on a per passenger basis than routes in an area of more dense coverage. Accordingly, policies that relate to public support of intercity bus service should be route specific and consider the effects of alternative services.

The behavior of the model can be further illustrated by looking at the disutilities for particular stops along the routes. Figures 6 and 7 show the disutility savings of southbound bus service for each of the routes. In these diagrams the *DU* savings for automobile and the alternative bus service are shown as bar charts for each station and the preferred choice is shown as a line. For the Green Bay–Milwaukee route alternative, bus service is preferred to the automobile for the first three stops on the route (De Pere, Saint Norbert, and Greenleaf). Beyond that point automobile would be the best choice as an alternative to the original intercity bus service. The Ashland-Abbotsford route shows a similar pattern; however, the automobile is better than the alternative bus in all cases except at the beginning of the route at Ashland. For stations near the south end of the routes (beyond Waldo or Prentice), the automobile has a disutility advantage over the original service for southbound trips (i.e., the benefits of intercity bus are zero for those stops). These stops have a positive benefit for northbound travel. In general, it appears that direct automobile travel has an advantage over intercity bus for relatively short trip lengths.

SENSITIVITY ANALYSES

To get a better feel for the model performance, extensive sensitivity analyses were conducted on key parameters of the model. These were modal choice parameters (value of time and out-of-vehicle time multiplier), user characteristics (percent captive), and modal characteristics (automobile cost and bus out-of-vehicle time per trip). The results of these analyses follow.

Choice Parameters

Results of varying the disutility equation coefficients are shown in Figures 8 and 9. High values of time (Figure 9) indicate a user who is willing to pay more for high speed, and a high out-of-vehicle time multiplier indicates a traveler with a concern for convenience. An increase in the value of time causes a reduction in the benefits index with the index reaching a value of zero at a value of time of $17.00 per hour on the Green Bay–Milwaukee route and $32.00 per hour on the Ashland-Abbotsford route. The rate of change of the index is moderate with a range of +13 or +38 percent to −7 or −20 percent as the parameter is moved up or down 50 percent from its base value.

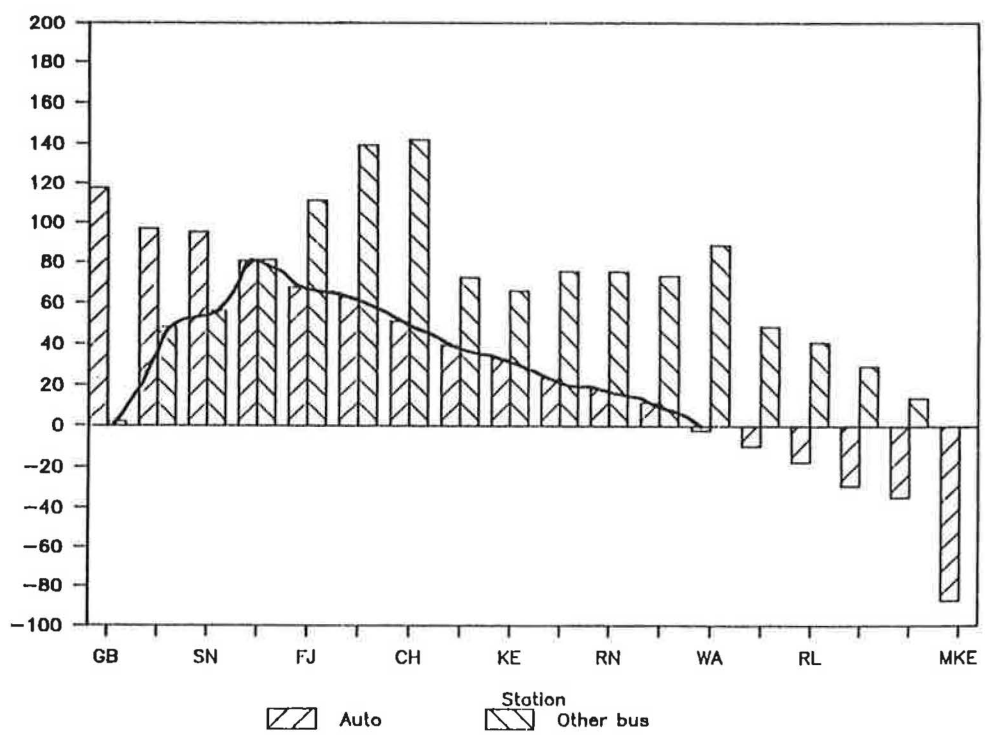

FIGURE 6 Station analysis: Green Bay–Milwaukee via Plymouth (solid line represents least disutility alternative at each station).

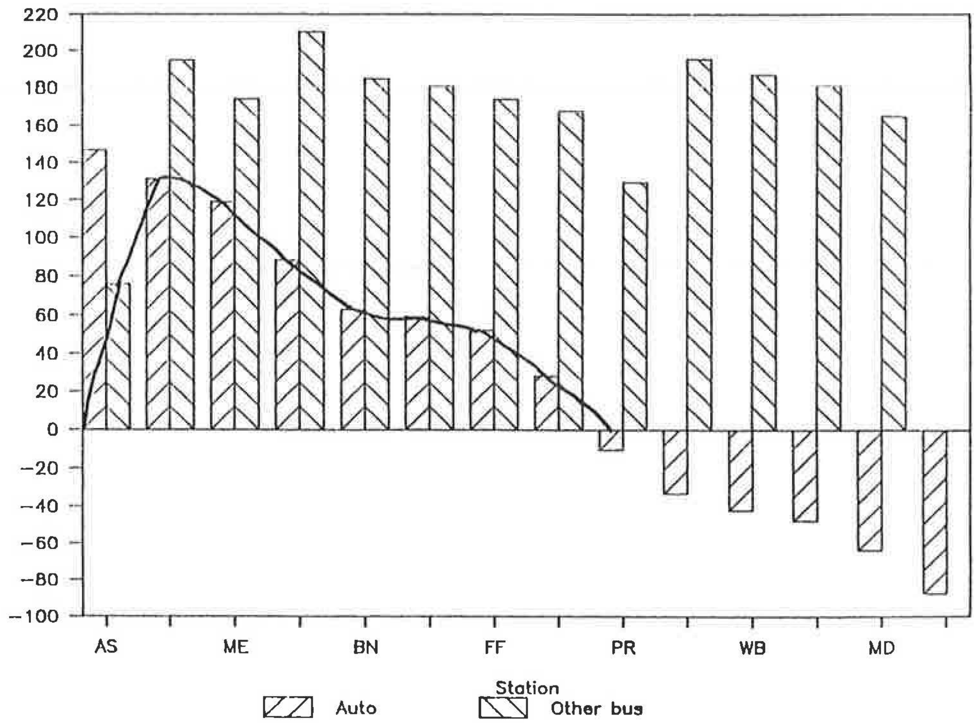

FIGURE 7 Station analysis: Ashland-Abbotsford.

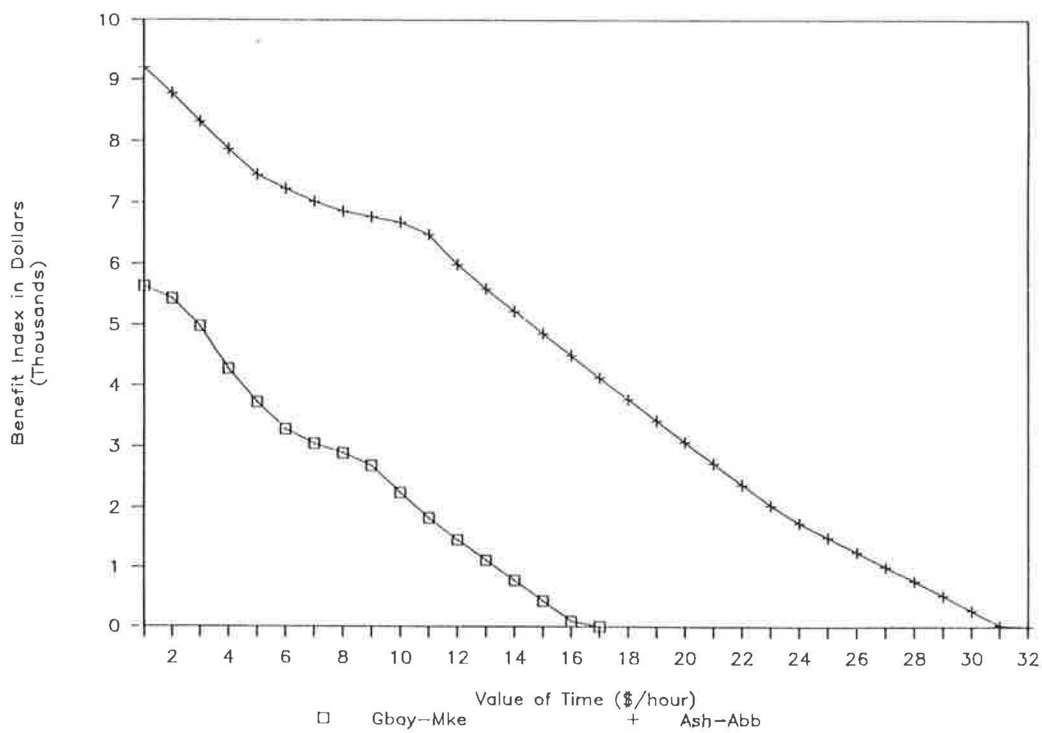

FIGURE 8 Vary value of time.

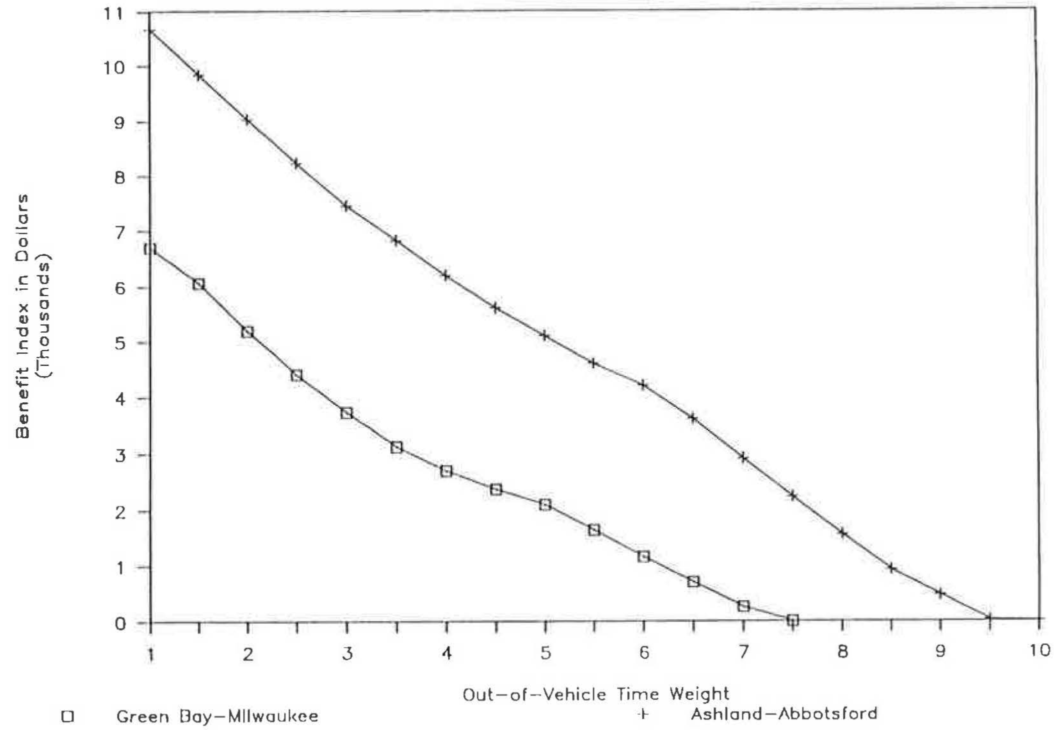

FIGURE 9 Vary out-of-vehicle time weight.

The out-of-vehicle time weight also shows an inverse relationship with the benefits index declining as out-of-vehicle time gains in importance (Figure 9). The benefits index reaches zero with values of C_1 at 7.5 and 10.0 for the two routes. The model is somewhat more sensitive to this parameter with a change of +21 or +62 percent to −25 or −36 percent with a change of the parameter up or down by 50 percent.

User Characteristics

The analysis used a base value of 50 percent captive users for intercity bus services. The concept of captive riders is complex because there are different circumstances in which an automobile is available or not available for a trip. For example, there may be an automobile for a college student to use to go to college but its use would prevent others in the family from using the car while the student was away. Data from the 1985 Wisconsin Intercity Bus Passenger Survey indicate that 49 percent of the users surveyed could not make a trip if bus service were not available that day and 16 percent would be unable to make similar trips if the bus service were permanently eliminated. Results of varying the percentage of captive users are shown in Figure 10. The benefits index increases directly as the percentage of captive riders increases. The changes have a moderate to relatively small effect with a range of +21 or +26 percent to −19 or −25 percent with a change of 50 percent above or below the base value.

Modal Characteristics

Two modal parameters, bus out-of-vehicle time and automobile cost, were varied. These results are shown in Figures 11 and 12. For the base situation, automobile trips had an out-of-vehicle time of 5 min and bus trips had an out-of-vehicle time of 15 min for the intercity segment. Bus intercity out-of-vehicle time was varied as shown in Figure 11. Here the benefits index declines as out-of-vehicle time increases. The rate of change is moderate with changes of +21 or +40 percent to −17 or −27 percent with a ±50 percent change from the base value.

The cost of automobile travel has a major effect on the calculations as shown in Figure 12. When automobile costs are set equal to bus costs (14 cents/mile) the benefits index goes to zero for both routes. The index increases rapidly as automobile costs increase. The index changes by +112 or +153 percent to −100 percent as the cost of automobile travel is varied by 50 percent above and below the base value. These major changes occur because the chief advantage of intercity bus over the automobile is its reduced cost. When this advantage disappears with equal costs, all benefits also are gone.

Interpretation

The sensitivity analysis shows how the benefits of intercity bus service are related to route location, user characteristics, modal characteristics, and choice parameters. The analysis indicates that benefits of service are highly sensitive to the location of the bus route relative to other routes and to the cost of automobile travel. Other factors such as value of time, out-of-vehicle time weight, out-of-vehicle time, and percentage captive users have a more moderate effect.

It should be noted that the relative benefits of the two bus routes remained nearly the same throughout the analysis. That is, the Ashland-Abbotsford route had an index roughly twice that of the Green Bay–Milwaukee route under a wide variety of values for the various parameters. This indicates that the basic

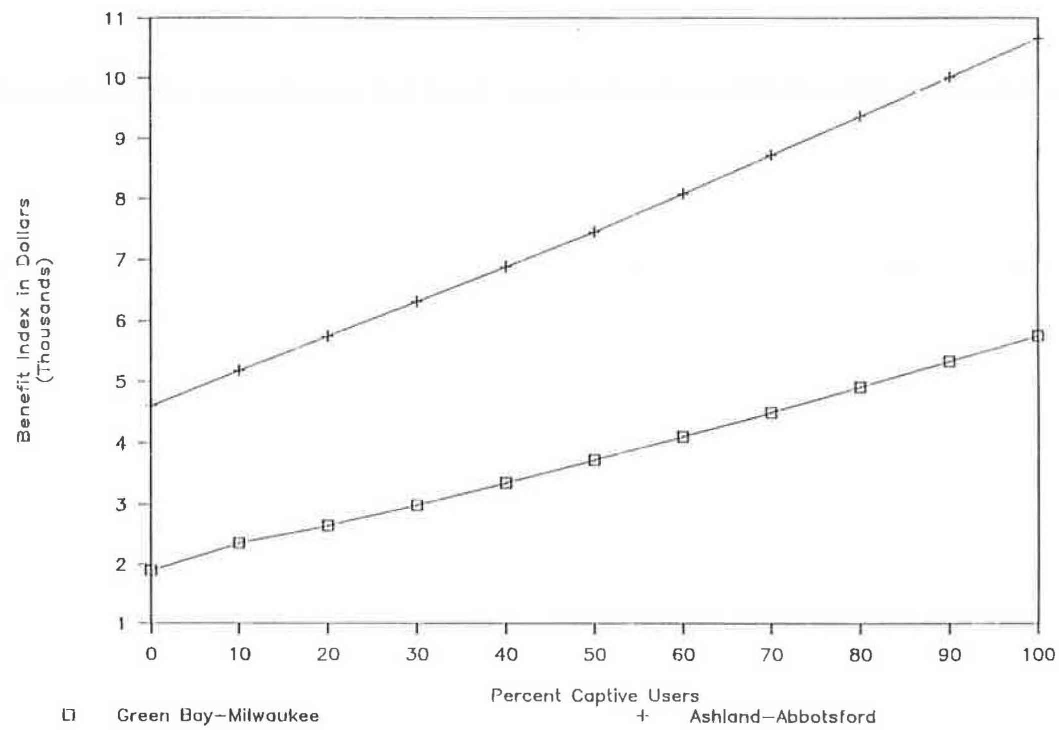

FIGURE 10 Vary percentage captive.

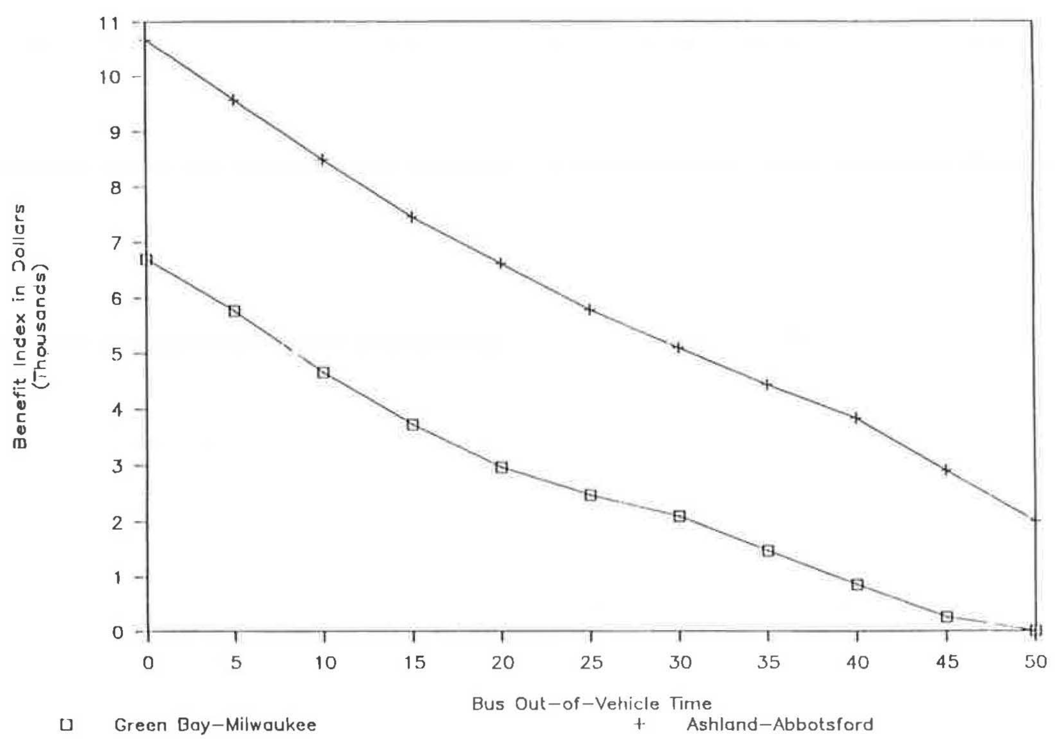

FIGURE 11 Vary bus out-of-vehicle time.

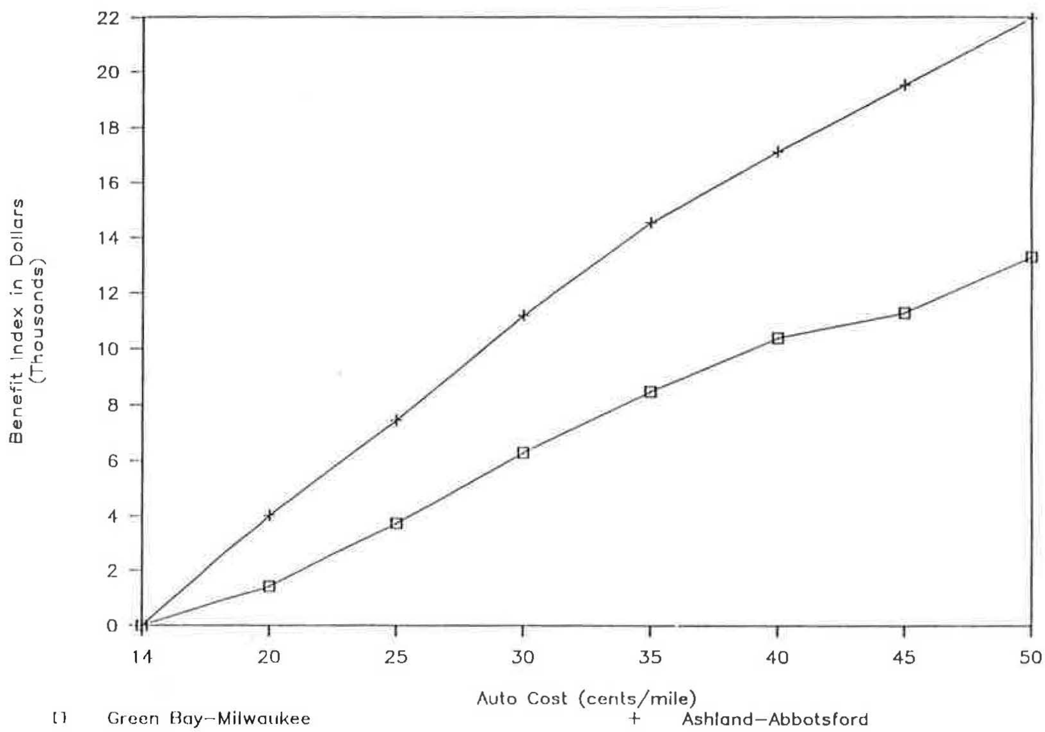

FIGURE 12 Vary automobile cost.

difference in routes results from route location and length rather than assumptions in the model. This result is good for present purposes in that it indicates that the model can be used to determine the relative importance of routes quite independently of assumptions necessary for model operation. Different parameter values affect different routes in the same way and thus do not appear to affect the relative importance of each route as measured by the benefits index. Thus the model may prove to be a useful tool for the selection of routes for public support.

CONCLUSIONS

This paper has provided a look at the benefits of intercity bus service. These benefits were estimated by a benefits index that calculates user benefits as a function of the characteristics of bus and automobile services, the characteristics of users, and choice parameters. Benefits of intercity bus service include savings in user cost, time, and inconvenience; the opportunity to ship commodities of a size or nature not permitted by other carriers; the availability of an option to automobile users; merit value; and the perception of community accessibility.

From the model developed to assess the benefits to users it was found that the level of benefits is highly sensitive to the location of the route relative to other routes. Those intercity bus routes that are isolated from other routes have a higher overall benefit than those that are located near other routes. Automobile cost also has a major effect. Benefits of bus service increase at about twice the rate of increases in automobile costs. Other factors such as value of time, out-of-vehicle time multiplier, bus out-of-vehicle time, and percentage of captive users have more moderate effects on the level of benefits. The level of benefits changes about half as fast as the rate of change in these parameters.

The research has several implications for policy on intercity bus service. If intercity bus service is to receive public support, it appears that support should be provided differentially for different routes and services. An important consideration should be the location of the route relative to other routes and the degree to which the users of the service have no other choices available to them. Important considerations in evaluating whether there should be a state program on intercity bus service include the following:

1. What is the impact on passengers, shippers, and others if bus service is discontinued?
2. To what extent will costs be shifted to the public sector for individuals unable to adjust to the loss of service?
3. What alternatives exist for the provision of mobility if service is lost?

It is recommended that state agencies trying to answer these questions analyze all services in the state according to the procedure outlined in this paper. By using such an approach a rational policy toward intercity bus service can be developed.

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REFERENCES

1. F. D. Fravel. Intercity Bus Service Changes Following the Bus Regulatory Reform Act of 1982. In *Transportation Research Record 1012*, TRB, National Research Council, Washington, D.C., 1985, pp. 38–46.
2. C. Oster and K. Zorn. *The Impacts of Regulatory Reform on Intercity Bus Service.* University Research Office, U.S. Department of Transportation, 1984.
3. M. Kihl. The Impact of Bus Deregulation on Small Towns. In *Transportation Research Record 1012*, TRB, National Research Council, Washington, D.C., 1985, pp. 65–71.
4. M. Kihl. *Alternative Responses to the Needs for Intercity Buses in Rural Areas.* M.S. thesis. Design Research Institute, Iowa State University, Ames, 1985.
5. R. G. McGuillivary. Should the Intercity Bus Industry be Subsidized? *Traffic Quarterly*, Vol. 33, No. 1, 1979, pp. 99–115.
6. E. Hansen, E. Beimborn, J. Morck, J. Williams, and J. Zarr. *Assessment of the Benefits of Intercity Bus Service in Wisconsin.* Transportation Policy Studies Institute, University of Wisconsin, Milwaukee; Wisconsin Department of Transportation, Madison, 1986.
7. M. Wohl and B. V. Martin. *Traffic Systems Analysis.* McGraw-Hill, New York, 1967.
8. H. D. Mohring and M. Hartwitz. *Highway Benefits—An Analytical Framework.* Northwestern University Press, Evanston, Ill., 1962.
9. M. L. Manheim. *Fundamentals of Transportation Systems Analysis*, Vol. 1: *Basic Concepts.* The MIT Press, Cambridge, Mass., 1979.
10. D. J. Harmatuck. Referendum Voting as a Guide to Public Support for Mass Transit. *Traffic Quarterly*, Vol. 30, No. 3, 1976, pp. 347–369.
11. C. L. Stevens and P. R. Norris. The Role of the Intercity Bus Industry in Isolated Rural Regions of Oregon. *Transportation Research Forum*, Vol. 24, No. 1, 1983, pp. 535–541.
12. A. L. Hansen. *External Effects of Improvements in Urban Public Transportation.* M.S. thesis. Boston University, Boston, Mass., 1986.

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