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Abridgment

Public Attitudes Toward Automobile-Restricted Streets in Philadelphia and Trenton

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An evaluation of the effectiveness of automobile-restricted zones as a transportation system management strategy to improve mobility in activity centers is the subject of a study conducted in the Delaware Valley region. Attitudinal surveys were used to compare two automobile-restricted zones in the region: the Chestnut Street Transitway in Center City in Philadelphia and the Trenton Commons Mall in downtown Trenton, New Jersey.

Separation of pedestrian and vehicle traffic has been applied successfully in many European urban centers since the 1950s. It is only recently that the technique has gained popularity in the United States (1). The objective of automobile-restricted zones is to improve commercial vitality, environmental quality, and traffic conditions in urban centers. At the same time, they save energy by encouraging public transportation and nonautomobile modes of travel and create a safer and more relaxed atmosphere for pedestrians.

A review of the literature indicates that the general response to automobile restriction and pedestrian-transit improvements has been favorable. Nearly all participating cities have initially experienced a reluctance to participate in such programs, particularly from merchants but, after a period of experimentation, adaption, and evaluation, a consensus of support is evident. Whenever aggressive programs have been pursued with public and private cooperation and involvement, the image of the downtown area is visually more pleasing and economically more viable (2).

The underlying hypothesis in this study is that the strategy of an automobile-restricted zone may have varying effects depending on the prevailing conditions. The mercantile composition and the economic vitality of the activity center, its perceived safety and relative accessibility, and the physical and operational design of the automobile-restricted zone have been identified as the critical independent variables.

The survey questionnaire was chosen as the most appropriate technique in view of the other available data. Results from a survey conducted among employees in the Chestnut Street Transitway area are compared with information provided by the city of Trenton that was gathered through an independent attitude survey of downtown employees. Another survey polled the Chestnut Street merchants and compared results with a pretransitway survey.

CHESTNUT STREET TRANSITWAY

Center City in Philadelphia covers approximately 5 km^2 (2 $miles^2$), represents the center of a nine-county region with a population of more than 5 000 000, and provides the focus of office, commercial, and cultural activity for 300 000 employees. Recent rehabilitation efforts have strengthened its vitality and increased its relative attractiveness.

Chestnut Street has always been one of the city's finest shopping streets. The main office building complex around Broad Street and the historic monuments on the east end generate additional large volumes of pedestrian and vehicle traffic that create serious traffic congestion problems. The city of Philadelphia began actively to investigate the feasibility of the Chestnut Street Mall in 1956 (3). Although planners, elected officials, and large businesses with a stake in Center City's future were proponents of the mall, hundreds of small, prospering merchants were opposed to it. Planning for the Philadelphia bicentennial celebration revived interest in the mall idea and served as a catalyst to implementation.

In May 1975, Chestnut Street became the transitway. There were two-way bus operations between 18th and 6th streets, and other motor vehicles were excluded. Sidewalks were widened, and special fixtures such as lighting, trees, and various street furniture were added. The project cost $7.4 million and was funded through a capital grant from the Urban Mass Transportation Administration (UMTA).

Survey of Employees

A questionnaire was designed to collect data on employees' attitudes toward the transitway and the downtown area (4). The survey was limited to directly affected employees who work in the two-block area immediately adjacent to the transitway (Market to Walnut streets) from 18th Street to 6th Street. Of 15 000 questionnaires distributed to 141 firms during February 1976, 5285 completed questionnaires were returned.

The survey results show that there is common agreement that daytime pedestrian traffic on Chestnut Street has increased; however, there are no prior pedestrian counts to document this. More than 60 percent of respondents indicated that they walk and do more shopping on the transitway than on other streets. Twenty-two percent were influenced by the transitway to ride buses on Chestnut Street rather than other streets even though statistics show that, contrary to anticipation, transitway bus travel time has increased. Twenty percent of the respondents reported patronizing eating establishments on Chestnut Street more than on other streets.

The results of the employee survey suggest that the transitway was successful in accomplishing its indirect goals of improving the commercial vitality and environmental quality of Center City. An overwhelming majority (76 percent) of the respondents agreed that the transitway was successful in creating a more relaxed atmosphere for pedestrians. Sixty-six percent thought that the facility preserved or improved the commercial vitality of the city. Sixty-five percent also agreed that the transitway achieved its goal of improving the environmental and aesthetic quality of the city.

The main goals of the transitway planners were to improve traffic conditions downtown and to encourage public transportation. Fifty-two percent of the respondents said that traffic conditions improved, and 44 percent agreed that the transitway encouraged the use of public transportation and nonautomobile means of travel. Combined with the fact that a relatively small portion of the respondents were influenced to ride public transportation on the facility more frequently, it appears that the transitway has not yet lived up to its transit expectations.

The strongest argument in favor is that there is common agreement among respondents (75 percent) that the transitway should not be opened to automobile traffic again. Provision for more parking facilities adjacent to the corridor was a popular recommendation: Sixty-one percent favored the measure, and 58 percent were opposed to the option of allowing private automobiles after working hours. Another interesting finding was that more than half of the respondents are against further restriction of automobiles on other downtown streets.

The responses to the other recommendation regarding restriction of use to pedestrians only was mixed. Lower income users, who are much more dependent on bus transportation, are against any restriction of bus traffic.

A feeling of dissatisfaction was communicated through the write-in recommendations on excessive bus speed between stops, reckless driving, and two-way operation, which was viewed as a potential hazard to pedestrians. The size and poor condition of buses as well as excessive noise and pollution levels were also subjects of complaint.

The attitudes of respondents toward Center City were very interesting. Eighty-nine percent of the respondents who commute to work use some form of public transportation. Forty percent of them do more than half of their shopping downtown and feel that one of the strongest advantages of Center City is that it offers a greater variety of merchandise. The lack of convenient and free parking was rated a very serious problem. As the distance of the residence from Center City increased, there was less enthusiasm about the advantages and more concern about the problems of the downtown area.

Survey of Merchants

Wearing apparel and miscellaneous retail businesses account for one-third of the 258 commercial establishments along the transitway. Eating and drinking establishments come next and are followed by banking and financial institutions. Eleven furniture and equipment stores, two department stores, two hotels, two movie theaters, and two parking garages and lots are scattered along the transitway. Most establishments tend to be small, employing 10 or fewer persons.

The closing of Chestnut Street to automobile traffic has had a great impact on the composition of commercial establishments along the street. New, nationally known chain stores have moved in and contributed to the economic stability of the downtown area while borderline shops have been forced out because of increased rents. The crowds on the street have attracted entertainers who perform on the sidewalks.

A survey of all merchants was undertaken to assess the effects of the transitway on customer accessibility, business activity, and deliveries. A successful personal distribution and collection of the questionnaires resulted in 72 percent of the forms being completed.

Seventeen percent of businesses moved in after the completion of the transitway, and only one-third of these considered the transitway a major factor in their location. About 3 of every 10 merchants generally felt that the transitway had prompted them to make changes or renovations in their stores.

More than half of the merchants surveyed expressed an overall favorable attitude toward the transitway, and approximately one-quarter voiced an unfavorable comment. Overall, large businesses were more favorable than small establishments. The banking and financial institutions were 70 percent in favor. On the other hand, furniture and equipment stores, eating and drinking places, and miscellaneous retail stores were less favorable.

A telephone survey taken by Philadelphia '76 before construction of the facility reported approximately 80 percent of the 200 merchants who responded to be in favor of the project and 13 percent opposed. A comparison of the before and after responses of the same firms indicates that the implementation of the transitway has changed formerly favorable attitudes to indifferent or unfavorable. Evidently, the transitway did not meet the expectations of some merchants. About 60 percent of those merchants who are now unfavorable were once in favor.

Thirty percent of the merchants surveyed felt that business activity had increased since the opening of the transitway, another 30 percent felt it had remained the same, and 25 percent said it showed a decrease. Almost all those who indicated an increase in business also expressed a favorable overall attitude but were evenly divided as to the change being a result of the transitway. The majority of those merchants who indicated a decrease in business activity voiced an unfavorable attitude, and almost all of them attributed this change directly to the transitway. Business activity is very much a function of the type of business. Sales of wearing apparel increased, but eating and drinking places lost business.

The majority of the merchants responded that accessibility of customers to their stores had either become more difficult or at least had remained the same. Generally, stores that depend on pedestrian access felt there was an improvement in accessibility, and stores that depend on automobile accessibility seemed to be negatively affected. Several merchants, especially small, miscellaneous retail stores, felt that the automobile traffic during night hours provided shoppers with a sense of security that cannot be compensated for by buses alone. Merchants are more in favor of providing more parking facilities than increasing transit service for their customers.

Finally, the problem most frequently expressed was bus speed and two-way operation. In general, there was common agreement that pedestrian traffic increased and that the general environment or the aesthetic quality of the street had been improved.

Most merchants responded that the transitway had had no significant impact on their deliveries. Smaller stores were seen to be at a disadvantage because they cannot control the time of delivery of goods and often have no rear access. The most frequent suggestion made for improving deliveries was to permit trucks onto the transitway during off-peak hours.

TRENTON COMMONS

Trenton, the capital city of New Jersey, is the center of the state, county, and city government. Trenton's population has recently declined, and its composition has changed drastically. However, its employment has grown slightly because of the expansion of state office functions.

The Trenton central business district (CBD), an area of only 2.5 km^2 (1 $mile^2$), provides jobs for 30 000 private and government employees and offers a large percentage of the city's retail trade. Increased competition with new suburban shopping malls has resulted in a decline of downtown Trenton as the regional shopping center.

The Trenton Commons was planned as a comprehensive scheme aimed at revitalizing the downtown area. The two-block section of State Street between Warren and Montgomery streets, where most of the downtown commercial activity is concentrated, was closed to traffic and a pedestrian mall was created. It was expected that the mall would generate additional private investments, but these never materialized. The project was implemented in September 1974. Its cost of $1.96 million was funded through a community development grant from the U.S. Department of Housing and Urban Development, city tax revenue, and state funds.

The city of Trenton Department of Planning and Development conducted a survey of downtown Trenton employees. The idea to poll consumer attitudes on several alternative solutions about downtown Trenton originated with the organization of downtown businessmen. During August 1976, 25 000 questionnaires were distributed to all government employees and to a few private downtown firms. More than 6000 questionnaires were returned by mail; 3000 of these were systematically selected and processed.

The survey results indicated that the majority of employees who responded avoid the downtown area (5). Forty percent bought lunch downtown and 33 percent shopped more frequently than once a week; only 13 percent did more than one-fourth of their shopping downtown and 67 percent did not do much shopping at all. Thirty-six percent never used downtown banking services. The area was rated poor compared with other shopping areas by 58 percent of the respondents.

Too many loiterers and rowdy youths were the two most serious problems. Safety was the third problem most frequently mentioned among those who shopped less frequently; those who shopped more frequently did not consider safety to be so important. Originally, the mall did contain outdoor seating areas and other amenities, but they were removed after 2 years because merchants complained that the setup encouraged loitering.

Parking problems were also seen as serious by more than half of the respondents. Lack of knowledge about the downtown area was striking. Of those who most often drove downtown, 67 percent did not know about the existence of free parking. A field survey indicated that, since Trenton Commons was implemented, commercial activity had not shown signs of the major improvements anticipated.

As a response to the survey, the downtown merchants decided to implement two subsidized experimental bus routes to shuttle workers from the outskirts of the downtown area to the commons during their lunch breaks. The experiment was successful in increasing patronage of the mall.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The findings of this study indicate that there might be some validity to the hypothesis explored, and further investigation is warranted. Transportation facilities are perceived differently and have different effects on the attitudes and behavior of individuals depending on the surrounding environment and prevailing conditions in which they are experienced and the individuals' expectations. The case of Trenton Commons has shown that restricting automobiles cannot by itself reverse a situation or a trend of decay in downtown areas that are no longer viable centers. In Philadelphia, a relatively healthy and viable environment, the transitway survey has shown that people see automobile restriction as an effective tool in preserving and further improving the commercial vitality and the environmental quality of the downtown area. In order for a transit improvement to have a significant impact, it must either present an intriguing new image or rally public support. The implications of these findings seem to deserve a wide audience among transportation planners who are working on automobile-restricted zones.

There is a general need for better understanding of user behavior and how it relates to public transportation improvements. Previous research has dealt primarily with aggregate changes in physical and economic indexes (6). Little attention has been given thus far to microanalytic social and behavioral analyses. There is no single design and operation that will fit in all environments and satisfy all users. Therefore, knowledge of the local needs and potential use of the facility can be useful in the planning, design, and management of the project.

Another conclusion of this study is that the concept of the transitway mall seems self-contradictory. It provides neither the relaxed atmosphere of a pedestrian mall nor the efficiency of a transit thoroughfare. If the objective is to discourage through traffic, other alternatives such as the "traffic cell" concept should be further explored (7).

Certain recommendations emerge from the analysis of the survey results (4). In the case of the Trenton Commons, the problem lies in the poor image of the downtown area. Solutions should aim to improve the unsafe image and to strengthen the retail and service base. In the case of the Chestnut Street Transitway, the problems lie in the fact that certain actions—physical and operational improvements aimed at utilizing the project—have not been taken yet. Suggestions for further study include improvements of bus operations through proper signalization and reassignment of bus routes, relaxation of restrictions to allow private automobiles after working hours, the establishment of flexible regulations on deliveries, and provision of convenient, short-term, special-purpose parking facilities. A second category of recommendations includes substituting small, noiseless, and more pleasant looking vehicles for the current buses, adding outdoor activities, and improving and integrating overall city transit services.

Many important issues were only touched on here. There is an apparent need for further research on business activity patterns, change in the behavior of pedestrians and transit riders, and attitudes and opinions of users of the facility who are not downtown workers. Without a control group and baseline data, it is difficult to draw objective conclusions. Finally, because the technique of attitude surveys is limited by its very nature, supplementary indirect evaluation techniques are necessary.

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Density as a Determinant of Highway Impacts

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The effects of superhighways in established residential areas in 23 standard metropolitan statistical areas in nine states are reported. Comparisons are made between affected and unaffected census tracts for 34 population and housing variables by using information from the U.S. Census for 1960 and 1970 and from state highway departments. The analysis tool is multiple regression, which permits statistical control for tract location and "history." Regressions were run separately for high- and low-density tracts, and housing density was posited as a conditioning factor of highway impact. Results indicate (a) substantial differences between affected and unaffected tracts in high-density tracts but not in the low-density stratum and (b) that despite these differences the highway impact variable accounts for little of the variance in the dependent variable. The latter finding implies that highways are of minor importance in explaining changes in census characteristics compared with general demographic trends and deliberate policies in metropolitan areas.

In recent years, there has been increasing concern that the construction of public works such as airports, dams, office buildings, and highways may have profound effects on natural and social environments. Obviously, each project is designed to produce at least one environmental change, such as damming up water, rerouting a stream, providing a detention center, or facilitating transportation. In addition to such manifest aims, however, there may be secondary effects on the surrounding areas that are neither intended nor beneficial.

For example, a new airport, while improving regional and national transportation networks, may affect land and housing values close to the facility and may create bothersome noise for nearby residents. The potential for such troublesome side effects, especially from very large projects, lies behind the drive for studies to assess the environmental impacts of such construction.

A concrete manifestation of the current interest in impact assessments can be seen in the National Environmental Policy Act of 1969 (NEPA). Section 102 of NEPA requires the relevant federal agency to produce an environmental impact statement (EIS) that discusses the likely consequences of a major federally funded construction project (31). An EIS is seen as a tool to aid policy makers to make better informed decisions on a proposed action and to take steps to eliminate or minimize any harmful impacts likely to result from implementation.

An EIS is, however, an estimation of the likely consequences of a project. These projective statements are rarely, if ever, subjected to postconstruction verification. Each project is treated on an ad hoc basis, and there is a minimum of information as to what might be anticipated on the basis of past experience. What is needed to make such assessments more convincing is some basic research on the empirical effects of large-scale construction.

This research provides a description of selected types of social impacts that have resulted from the construction and operation of multilane, limited-access highways in some urban areas. Thus, it is an effort to fill a gap in our empirical knowledge of such effects. Besides informing the impact assessment process, this paper also explores the factors that contribute to demographic change in urban areas. Despite a number of theories of urban morphology and several research techniques, only rarely have man-made elements of the social environment been treated as independent variables, as causal factors in and of themselves (23). This study views highways as an impacting agent whose effects are reflected in census data for cities.

LITERATURE ON HIGHWAY IMPACT

Highways built through residential areas may have a variety of impacts. One may consider the financial and psychological costs to relocated individuals (4, 6, 11, 15), the pollution-related effects on those living in proximity to the road (5, 7, 12, 20), and of course the benefits to highway users. This research focuses on the "remaining neighborhood," defines and measures the amount and nature of change in the characteristics of population and housing, and isolates that portion of the change attributable to the road.

Most of the empirical work on remaining neighborhoods has dealt with the delineation of neighborhood boundaries and not with highway impacts themselves. There are many examples of these various approaches

(8, 9, 13, 14, 16, 21, 22). The most sophisticated effort to use aggregate, descriptive data in combination with perceptual and behavioral indicators to define neighborhoods and develop an index to measure change is that of Burkhardt, Lago, and Rothenberg (1, 2).

But in all these cases empirical evidence of highway-induced change is either lacking entirely or measured without the benefit of adequate controls for sources of change other than highways themselves. In addition, the number of cases involved is typically quite small. I will not attempt to do more here than mention the above studies and indicate my belief that quantitative data on highway impacts continue to be lacking for the types of change this study seeks to measure.

RESEARCH METHODS

The impact of highways on population composition and housing characteristics is explored here by using census tracts as the unit of analysis (27, 28, 29). In all cases, comparisons over time are made between equivalent geographic areas. A total of 1571 tracts from the following 23 standard metropolitan statistical areas (SMSAs) are included: Hartford and New Haven, Connecticut; Wilmington, Delaware; Boston, Fall River, Lawrence-Haverhill, Lowell, New Bedford, Springfield, and Worcester, Massachusetts; Detroit and Lansing, Michigan; Newark and Paterson-Clifton-Passaic, New Jersey; Binghamton, Buffalo, and Utica-Rome, New York; Dayton and Youngstown-Warren, Ohio; Erie, Reading, and Scranton, Pennsylvania; and Providence-Pawtucket-Warwick, Rhode Island. These SMSAs had experienced the start and completion of construction of new, four-lane-minimum, limited-access highways during the 1960s. Of the 1571 tracts, 284 incurred impact (impact is defined here in terms of a tract's 1960 boundaries having been touched or crossed by a highway built during the decade).

In the equations, the dependent variable is the 1970 census value for one of 34 descriptive variables for each tract. It is this 1970 value we are attempting to "predict." The three independent variables are (a) the 1960 counterpart of the 1970 descriptor variables inserted to provide control for initial differences among tracts; (b) a location variable LOC, which indicates the distance of a tract from the center of its SMSA (standardized to control for absolute differences among SMSAs); and (c) a highway impact dummy variable HWYDUM, coded 1 for impacted and 0 for nonimpacted tracts. The coefficients for this last variable will represent the net average difference between impacted and nonimpacted tracts on the dependent variable in question.

Admittedly, the model ignores other factors that contribute to change in tracts and that had their effects during the 1960s. Growth trends and policies that are reflected in the 1960 descriptors continue into the decade of the 1960s. Without an intensive city-by-city study, however, such factors cannot be incorporated into the model. Generalizability is deliberately sought over specificity on the basis that the model above is the best overall, parsimonious one for the impact experience.

It is hypothesized that tract housing density in 1960 is an important conditioner of the magnitude and nature of highway impacts. Information from city and regional planning departments and the National Planning Data Corporation was used to develop 1960 figures for housing units per unit of area. All tracts were then stratified into two groups, and high and low density depended on whether they fell above or below the median figure of 15.06 units/hm^2 (6.025 units/acre). The regressions described above were then run separately for each stratum.

RESULTS

The focus here is on two aspects of the statistical findings: the ability to distinguish between affected and unaffected tracts as indicated by the size and significance of the regression coefficients associated with the impact dummy variable and the amount of variance in the dependent variable "explained" by the impact dummy. Table 1 gives the results of the regressions for high-density tracts; Table 2 gives the results for the low-density stratum.

Looking first at the regression coefficients, one notices that in high-density tracts the unstandardized coefficient exceeds its standard error by a factor of at least two in 19 instances (out of 34) whereas the comparable figure for low-density tracts is 8. Hence, one can conclude that highway impacts are more strongly felt in the high-density stratum. Moreover, these significant coefficients in high-density tracts frequently exceed their standard error by a factor of three or four whereas this excess is rare in low-density tracts. The initial hypothesis of greater impact in higher density tracts is thus borne out.

High-Density Tracts

In the high-density stratum, it is possible to describe the pattern of impact in the following way. The coefficients are generated mainly through a loss of population and housing units in this stratum, and that loss is concentrated in people at the lower end of a socioeconomic continuum. There are significant differences between affected and unaffected tracts for all age categories. Most notably, it appears that families with children are less frequently present in affected tracts in 1970. In addition, it does not appear that these individuals were replaced by more affluent people. Median years of school completed, median family income, number of white-collar workers, number of families with incomes over $25 000, and number of college-educated people are not different for affected compared with unaffected tracts.

Likewise, housing losses occurred in a variety of housing categories. Both single-unit structures and units in structures of five or more units show significant, negative, net average differences between affected and unaffected tracts. Moreover, these units were not replaced since there is no indication of a difference in new construction (units built between 1960 and 1970) between the two groups of high-density tracts. The negative net difference in size of household in affected tracts (measured by median persons per occupied unit) reinforces the evidence on the relative absence of families with children.

The absence of significant differences between the two sets of tracts on variables that describe the better educated, white-collar, affluent population can be explained by various factors. These high-density tracts tended to be located closer to the city center where such people reside less frequently (the relation between status and distance of residence from the city center is far from perfect). Since these people are absent from these areas, they cannot be affected by a new highway. The lack of difference may also stem from the relatively small absolute number of people in the higher socioeconomic categories in 1960. For instance, only about 11 families were earning over $25 000 in 1960 in each high-density tract.

One might argue that highways are routed so as to avoid affluent sections of tracts and that this permits the impacts to fall on a politically less powerful segment of the population. On the basis of available information, this notion can be rejected. Correlations between the highway-impact dummy variable and various measures of socioeconomic status are close to zero whether one considers high-density tracts, low-density tracts, or all tracts together. In addition, although it is possible that highway engineers take population composition into account in planning routes, such social factors are certainly not the only—and most likely not the major—consideration in such decisions. Highways have to yield to topographic features and are generally routed in as straight-line a pattern as possible. Highway costs are figured per unit of distance. Routing a road around high-income areas within tracts could well result in higher costs in the end because of the circuitous path. Besides, the political impotence of inner-city residents is not total. Effective opposition to highway and other projects has been mounted in various types of neighborhoods, and inner-city residents during the 1960s had

Table 1. Highway impacts in high-density tracts.

		HWYDUM		LOC		1960 Census Descriptor	
1970 Census Dependent Variable	R^2	β	Variance Explained (%)	β	Variance Explained (%)	β	Variance Explained (%)
Total population	0.83	-670.20[a]	0.5	1251.51[a]	3.3	0.79[a]	79.0
		-0.109		0.092		0.894	
Nonwhite population	0.57	-565.46[a]	2.1	6.61	4.0	0.84[a]	51.2
		-0.110		0.001		0.745	
Population under 5 years	0.25	-77.12[b]	1.0	235.73[a]	2.5	0.27[a]	21.5
		-0.097		0.136		0.464	
Population aged 19 and under	0.71	-308.34[a]	1.1	232.66[c]	0.8	0.80[a]	69.0
		-0.122		0.042		0.832	
Population aged 55 and older	0.73	-97.75[b]	0.0	412.10[a]	5.9	0.79[a]	67.2
		-0.061		0.117		0.831	
Females aged 15 to 44	0.72	-114.21[b]	0.3	289.15[a]	2.3	0.87[a]	69.4
		-0.073		0.084		0.836	
Fertility rate	0.02	-6.23	0.0	79.17	0.2	0.07[b]	1.6
		-0.010		0.056		0.128	
Dependency ratio	0.04	5.53	0.2	-13.48	0.2	0.20[a]	3.2
		0.041		-0.045		0.178	
Married couples with own children under age 18	0.41	-77.17[b]	0.9	220.57[a]	6.5	0.64[a]	33.4
		-0.089		0.115		0.594	
Married persons	0.82	-240.47[a]	0.9	637.22[a]	7.0	0.70[a]	74.6
		-0.093		0.113		0.876	
Persons aged 5 and older residing in same house as 5 years previous	0.80	-323.92[a]	0.6	312.47[c]	5.8	0.83[a]	71.6
		-0.102		0.045		0.868	
Households residing at current address for less than 2 years	0.62	-66.57[b]	0.0	206.54[a]	0.2	0.84[a]	61.8
		-0.067		0.094		0.791	
Stability index	0.77	-271.16	1.3	-220.67	1.5	0.84[a]	73.8
		-0.034		-0.013		0.873	
Persons over age 25 with eighth-grade education or less	0.77	-123.33[a]	0.0	337.52[a]	0.7	0.56[a]	75.8
		-0.086		0.107		0.875	
Persons over age 25 who are college graduates	0.86	4.54	0.0	20.28	2.1	1.02[a]	83.7
		0.007		0.015		0.924	
Median years of school completed for persons over age 25	0.80	-0.057	1.1	-0.077	4.1	0.89[a]	74.5
		-0.015		-0.009		0.893	
Families with income under $10 000	0.83	-80.30[a]	0.4	76.51[c]	2.6	0.53[a]	79.7
		-0.083		0.036		0.901	
Families with income over $25 000	0.07	-4.21	0.2	25.73[b]	1.3	0.12[a]	5.1
		-0.042		0.117		0.226	
Median family income	0.60	42.34	0.5	-961.75[b]	2.8	1.36[a]	56.8
		0.008		-0.079		0.797	
Households owning no automobile	0.73	-99.31[a]	0.9	119.95[c]	0.6	0.74[a]	72.5
		-0.081		0.044		0.868	
Percentage of women in labor force	0.39	-0.19	0.00	7.02[a]	5.0	0.65[a]	34.3
		-0.008		0.139		0.592	
White-collar workers	0.83	10.42	0.0	-3.28	4.8	1.02[a]	78.0
		0.013		-0.002		0.911	
Blue-collar workers	0.67	-123.91[a]	0.5	200.85[a]	3.3	0.68[a]	63.3
		-0.112		0.083		0.802	
Total housing units	0.83	-146.45[b]	0.0	364.04[a]	1.7	0.86[a]	80.9
		-0.063		0.071		0.902	
Owner-occupied units	0.89	-33.12[c]	1.4	34.48	3.9	0.96[a]	83.3
		-0.028		0.013		0.935	
Units vacant and available for rent or purchase	0.38	-9.56	0.1	-52.61[b]	6.1	0.43[a]	31.3
		-0.041		-0.102		0.583	
Median persons per unit	0.67	-0.095[b]	3.0	-0.009	1.0	0.83[a]	63.4
		-0.067		-0.003		0.809	
Median rooms per unit	0.89	-0.037	3.5	-0.225[b]	2.5	0.94[a]	82.5
		-0.015		-0.040		0.946	
Median persons per room	0.42	-0.003	0.2	-0.002	0.8	0.63[a]	41.1
		-0.010		-0.004		0.649	
Single-family units	0.83	-59.99[b]	0.9	77.81[c]	0.6	0.76[a]	81.3
		-0.057		0.034		0.904	
Units in structures with five or more units	0.82	-66.84[c]	0.8	201.66[b]	0.3	0.88[a]	81.3
		-0.036		0.050		0.916	
Units built in last 10 years	0.08	-5.01	0.0	72.66	0.9	0.23[a]	7.4
		-0.010		0.069		0.273	
Median contract rent	0.62	2.38	0.1	19.30[a]	3.1	1.22[a]	58.9
		0.033		0.123		0.772	
Median value of owner-occupied units	0.67	411.07	0.0	64.32	4.2	1.32[a]	62.4
		0.025		0.002		0.817	

Note: N = 789; 115 affected.

[a]Coefficient at least four times its standard error. [b]Coefficient at least three times its standard error. [c]Coefficient at least two times its standard error.

their advocates in political decision making in metropolitan areas.

Low-Density Tracts

In the low-density set of tracts, one finds few significant differences between affected and unaffected tracts. Most important, total population and number of housing units show no net effects from highway construction. Obviously, this does not imply that construction required no demolition or displacement of population. But one would assume that losses that did occur were either minor or were balanced by gains over the decade and that this resulted in no net difference between affected and unaffected tracts in 1970. I suggest the following scenario to account for those differences that do appear.

Highway construction increases the value of the land that lies in proximity to the road. This land is afforded

Table 2. Highway impacts in low-density tracts.

		HWYDUM		LOC		1960 Census Descriptor	
1970 Census Dependent Variable	R^2	β	Variance Explained (%)	β	Variance Explained (%)	β	Variance Explained (%)
Total population	0.79	-166.82 -0.022	0.8	1880.14[a] 0.151	15.2	1.00[a] 0.839	63.3
Nonwhite population	0.55	-66.39 -0.026	0.0	-242.55[b] -0.060	2.9	0.95[a] 0.732	52.4
Population under 5 years of age	0.34	42.44 0.057	0.7	278.97[a] 0.231	11.9	0.24[a] 0.479	21.7
Population aged 19 and under	0.78	-106.27[b] -0.035	0.6	624.98[a] 0.127	14.6	0.89[a] 0.839	62.3
Population aged 55 and older	0.70	-5.54 -0.004	0.2	443.73[a] 0.193	9.3	0.93[a] 0.790	60.9
Females aged 15 to 44	0.77	-17.74 -0.010	1.1	415.11[a] 0.150	15.0	0.99[a] 0.823	60.7
Fertility rate	0.01	15.66 0.032	0.1	-55.61 -0.070	0.3	0.04[b] 0.103	1.0
Dependency ratio	0.06	-6.01[b] -0.077	0.7	-9.13 -0.072	0.8	0.16[a] 0.211	4.4
Married couples with own children under age 18	0.77	-27.02 -0.024	0.9	254.38[a] 0.137	17.6	0.88[a] 0.825	58.6
Married persons	0.80	-70.11 -0.020	0.8	901.79[a] 0.157	17.4	0.93[a] 0.838	62.1
Persons aged 5 and older residing in same house as 5 years previous	0.76	2.43 0.001	0.4	1552.13[a] 0.244	17.8	0.92[a] 0.785	58.0
Households residing at current address for less than 2 years	0.55	6.79 0.010	1.2	130.87[a] 0.118	5.9	0.98[a] 0.712	48.2
Stability index	0.13	-426.30 -0.053	0.2	4094.89[a] 0.312	10.4	0.02[a] 0.155	2.4
Persons over age 25 with eighth-grade education or less	0.78	-24.28 -0.024	1.1	201.37[a] 0.121	1.3	0.69[a] 0.877	75.2
Persons over age 25 who are college graduates	0.83	10.28 0.011	0.0	101.42[a] 0.069	10.3	1.18[a] 0.888	72.5
Median years of school completed for persons over age 25	0.81	0.064 0.019	0.0	0.215[b] 0.039	12.3	0.793[a] 0.884	68.4
Families with income under $10 000	0.76	-29.55[b] -0.041	0.8	82.02[c] 0.070	7.6	0.47[a] 0.859	67.7
Families with income over $25 000	0.36	6.03 0.019	0.0	121.81[a] 0.242	6.6	0.76[a] 0.542	29.2
Median family income	0.81	215.16 0.027	0.0	904.61[a] 0.071	7.2	1.43[a] 0.882	73.8
Households owning no automobile	0.70	-37.93[c] -0.080	0.2	-7.23 -0.009	2.4	0.75[a] 0.840	67.0
Percentage of women in labor force	0.37	1.31[b] 0.066	0.5	4.75[a] 0.149	0.2	0.67[a] 0.615	36.6
White-collar workers	0.74	28.13 0.027	0.3	259.06[a] 0.152	16.8	1.01[a] 0.800	57.5
Blue-collar workers	0.80	-12.35 -0.010	1.6	238.39[a] 0.117	7.6	0.98[a] 0.868	71.0
Total housing units	0.82	-55.40 -0.024	1.0	598.79[a] 0.162	12.8	1.07[a] 0.858	68.3
Owner-occupied units	0.89	-49.08[b] 0.026	0.3	265.25[a] 0.087	14.7	1.07[a] 0.913	73.8
Units vacant and available for rent or purchase	0.22	0.74 0.010	0.6	-7.50 -0.060	1.5	0.39[a] 0.454	19.8
Median persons per unit	0.75	-0.009 -0.008	0.0	0.096[b] 0.050	15.7	0.769[a] 0.846	59.6
Median rooms per unit	0.83	-0.018 -0.008	0.5	0.082 0.024	8.9	0.894[a] 0.903	73.6
Median persons per room	0.58	0.004 0.016	0.6	0.011 0.029	0.7	0.637[a] 0.760	57.1
Single-family units	0.87	-63.61[b] -0.032	0.2	288.54[a] 0.090	14.3	1.07[a] 0.904	72.6
Units in structures with five or more units	0.52	45.07[b] 0.066	0.8	175.66[a] 0.158	0.1	0.944[a] 0.726	51.0
Units built in last 10 years	0.27	6.76 0.007	0.2	323.54[a] 0.204	12.1	0.331[a] 0.406	14.3
Median contract rent	0.67	2.03 0.023	0.0	15.14[c] 0.104	6.6	1.47[a] 0.789	59.9
Median value of owner-occupied units	0.83	19.23 0.001	0.0	2018.30[a] 0.070	10.6	1.48[a] 0.889	72.5

Note: N = 782; 169 affected.

[a] Coefficient at least four times its standard error. [b] Coefficient at least two times its standard error. [c] Coefficient at least three times its standard error.

better accessibility to other parts of the metropolitan area—an important consideration given the generally more distant location of low-density tracts from the city center. The increased value of land requires that it be used more intensively or encourages such use. Note that affected tracts in this stratum show significantly fewer owner-occupied units, significantly fewer single-family units, and significantly more units in structures of five or more units. These three coefficients suggest the replacement of less intensive land users (single-family units) with more intensive land users (multifamily units). Between 1960 and 1970, 46.5 percent of all housing units built in metropolitan areas outside the central city were in structures of at least two units [the remainder being single-family units or mobile homes (30)].

Besides encouraging different land uses, highways also contribute to increases in the prices for land within a category of use. Thus, we find fewer low-income families or households without automobiles in the affected tracts. Admittedly, this is scanty evidence for such a conclusion, but it is suggestive.

DISCUSSION OF RESULTS

How does one account for the different patterns and magnitude of impacts between high- and low-density strata? I believe that the explanation lies in the distinction between the highway as a physical entity and the highway as a transportation facility. The former refers to the road as a physical intruder that necessitates demolition of housing and relocation of population, creates barriers to movement within neighborhoods, increases traffic around access and egress points, and generally pollutes the physical environment. The highway as a facility is a carrier of goods and population that provides access between different zones of the metropolitan area.

In the high-density tracts, which are typically located nearer the city center, the physical aspect of the highway predominates. In areas where there is a greater dependence on pedestrian movement, as hypothesized by Kriken, Bottiny, and Thiel (16), and where the highway is more visually intrusive, sensitivity to the road as a physical object would be greater. More people are likely to reside within any given distance of the road than would be the case in low-density tracts. Lower income and greater pedestrian dependency, more children walking to school, and more use of local neighborhood shopping facilities all contribute to the likelihood that a new highway will disrupt normal transportation routes, force people to take detours, and otherwise disrupt movement. In short, the more densely populated an area is, the greater the physical intrusiveness of any major construction project can be expected to be.

In high-density tracts, population differences between affected and unaffected tracts were high among those age and marital categories that reflect families with young children. Families whose children are approaching school age have a tendency to seek suburban, single-family housing and open space. Highways interrupt access routes within neighborhoods, preempt relatively scarce open space that might have been used for parks or playgrounds, and generally increase the "urbanness" of an area (a condition typified by congestion, noise, traffic, and the relative absence of open space and greenery).

All of these factors would generally be negatively evaluated by a family with children of school age who must walk to school and whose play patterns require more room than those of toddlers or infants. The impetus to seek suburban, single-family housing is strong for families whose children are moving out of infancy. A highway constructed through a densely populated neighborhood contributes significantly to the decreased desirability of that area for such families. This pattern is reflected throughout the regression equations generated for high-density tracts. Once the children begin to venture out alone, the quality of the neighborhood becomes more important to the parents.

There have been several major studies of the characteristics of mobile families and the characteristics that make individual housing units and neighborhoods attractive or unattractive. This body of research points out the importance of quiet, traffic-free streets and general environmental qualities in conditioning feelings about a neighborhood. Obviously, the desire for certain characteristics in housing units and neighborhoods is not a function of highway impact alone. We argue, however, that for families with young children the presence of a highway significantly increases the desire to move. In inner-city neighborhoods, which are typically renter dominated, there is a continuous out-migration of families to single-family units. In controlling for differences among these neighborhoods (tracts), the tendencies were even greater in those that experienced highway impact (3, 10, 17, 18, 25, 26).

In low-density areas, primarily in the suburbs, the physical impact of the highway is mitigated by the dispersion of the residents. Fewer people live close to the road. Construction requires the demolition of fewer housing units and the relocation of fewer people. Yet it is the accessibility of other parts of the metropolitan region, particularly the downtown area, that marks the influence of a highway in such tracts. Neighborhoods that already lie close to the downtown area benefit to a lesser extent from improved accessibility; they are already at or near the focal destination and their marginal gain is smaller. The ability to commute to other parts of the SMSA increases the attractiveness of low-density, suburban tracts, and their suburban qualities are less disrupted by the presence of a highway.

In short, the physical impact of a highway in such low-density areas is minimal. Pollution, for instance, simply does not affect that many people. To the extent that suburban areas are generally more automobile oriented, the highway serves a positive function. Employment and shopping are typically separated from residence in their location, and children are more often driven or take a bus to school. A new highway complements these patterns through improved accessibility.

CONCLUSIONS

In both Tables 1 and 2, the amount of variance in the dependent variable "explained" by the impact variable is extremely low, never exceeding 3.5 percent and more typically under 1 percent. This characteristic of the tables implies that, although affected and unaffected tracts can be distinguished for a number of variables, highways have only a marginal effect on population composition and housing stock.

Generally, the past is the best predictor of the future, indicating that demographic change occurs slowly. The highway occasionally makes a contribution to the shape of tract characteristics but plays a minor role. Certainly highway construction and widespread automobile ownership have played important roles in opening up peripheral areas of our cities. This study, however, involved areas that were for the most part developed before highway construction. I do not mean to deny the historical importance of highways in urban growth. But, within already-developed parts of our SMSAs, general demographic trends far outweigh the effects of highways.

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Attraction of Interstate Radial Freeway Corridors for New Office Sites

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The impact of Interstate radial freeway corridors on the location of new office developments in seven U.S. cities between 1970 and 1976 is discussed. Data indicate that in each of the seven cities greater growth of this type occurred outside the downtown core than in it. Growth of office sites compared with previous development ranged from 12 to 110 percent and averaged 24 percent in the core and ranged from 106 to 307 percent and averaged 207 percent in noncore areas. Growth expressed in gross square meters showed a similar pattern. Of the office development that took place from 1970 to 1976, the greatest proportion of new sites occurred in Interstate radial corridors (average of 34 percent). When gross square meters of new office development was analyzed, growth on Interstate radial freeways exceeded growth in all noncore transportation corridors but not in the core itself. An analysis of other factors theoretically associated with these patterns suggests that accessibility to the residences of white-collar workers, especially those who make decisions on office location, was most important. Other factors examined—including accessibility to the city core, metropolitan tax differentials, and the cost and availability of land—were found to be unrelated or much less significant.

Completion of the Interstate highway network in American metropolitan areas has opened a wide variety of locational options for urban land use. New office sites have been prominent among these developments. The purpose of this study is to compare Interstate radial freeway corridors with other locations in seven metropolitan areas to determine their relative attraction for new office sites in the period between 1970 and 1976. The seven metropolitan areas studied are Atlanta, Dallas, Denver, Louisville, Minneapolis-St. Paul, Omaha, and San Jose.

DEFINITIONS

In this study, an office site is one in which the prime functions of the units that occupy it are the creation, storage, and dissemination of information on services performed, goods held or transferred, and personnel employed. A site may comprise a single office building, an office park of several buildings, or a complex of buildings built by the same developer in a limited time period. A service may be performed at the same location—e.g., physicians see patients and insurance agents sell policies—but rarely is the good for which the records are surrogates present at the office location. No steel ingots, for example, are found in the headquarters building of U.S. Steel.

The study includes office sites that are both renter-occupied and owner-occupied. It excludes all office sites that are wholly occupied by federal, state, and local government agencies whether these buildings are leased from the private sector or not because it is assumed that decisions on the location of government offices are usually made under a set of constraints different from those in the private sector. The study also excludes corporate headquarters located at the site of production facilities. Buildings with less than 2324 m^2 (25 000 ft^2) of gross floor area are excluded from the study. This allows the establishment of a manageable universe of sites within the metropolitan area of each city. It also permits the study to make maximum use of some existing public and private agency inventories that provide relevant data only on office sites in their cities that contain at least 2324 m^2 of gross floor area.

An Interstate radial is defined as a federally funded Interstate highway anchored at or near the central business district (CBD) of that metropolitan area. It extends outward from the CBD like a spoke of a wheel and, in most cases, intersects the Interstate circumferential highway. A non-Interstate radial has the same geographic pattern as the Interstate radial but is not necessarily a limited-access route. A radial corridor is defined as that area that lies within 1.6 km (1 mile) on either side of a radial highway and extends from the CBD to a point 6.4 km (4 miles) beyond the Interstate circumferential. A corridor 3.2 km (2 miles) wide is also developed along the Interstate circumferential in each metropolitan area. In some of the metropolitan areas, the circumferential is not composed entirely of Interstate routes. The short segments of state routes used to close the circumferential are in this study included as part of the Interstate circumferential.

Each of the metropolitan areas studied contains a cluster of downtown office sites that coincides roughly with the CBD. In no case, however, does this cluster extend linearly more than 2.2 km (1.4 miles), and in most it is less than 1.6 km (1 mile). Consequently, it is possible to enclose the downtown cluster in every metropolitan area in a circle whose radius is 1.1 km (0.7 mile). The CBD as defined in the Census of Retail Trade might be used as the base for some metropolitan areas, but in others it is not spatially coincident with the cluster of downtown office sites. In this study, the term "core" rather than CBD is used to designate the downtown office area.

The noncorridor area comprises all space inside a line 6.4 km (4 miles) from the Interstate circumferential, space that is not included in one of the types of spatial units described above. The number and types of the spatial units described above and the square kilometers they contain in each metropolitan area are given in Table 1. They also appear individually on the maps shown in Figures 1 through 7 (distance scales on these maps are given in U.S. customary units).

The period from 1970 to 1976 was selected for study because for most of the metropolitan areas it marks both the completion of the Interstate system and a sharp increase in development of office sites (Table 1).

SELECTION OF METROPOLITAN AREAS

The 7 metropolitan areas studied were selected from among 60 standard metropolitan statistical areas (SMSAs) that met the following criteria: (a) a central city population of at least 100 000 but fewer than 1 million inhabitants, (b) a central city with at least one core-anchored Interstate radial that was toll-free and that contained at least three interchanges between the

Table 1. Number and area of five types of development locations in the seven metropolitan areas studied.

	Atlanta		Dallas		Denver		Louisville		Minneapolis-St. Paul		Omaha		San Jose		Total	
Location	Number	Area (km^2)	Number	Area (km^2)	Number	Area (km^2)	Number	Area (km^2)	Number	Area (km^2)	Number	Area (km^2)	Number	Area (km^2)	Number	Area (km^2)
Interstate corridors	5	311.8	4	255.1	4	228.7	2	100.0	5	288.8	1	47.9	2	62.4	23	1294.7
Non-Interstate corridors	4	207.2	4	225.3	3	138.6	2	98.4	5	293.7	1	49.5	4	162.4	23	1175.1
Interstate circumferentials	1	207.2	1	227.9	1	50.5	1	55.7	1	295.2	1	76.1	0	0	6	912.6
Core and core extensions	1	11.7	1	7.0	1	7.0	1	3.9	2	7.8	1	3.9	1	3.9	8	45.2
Noncorridor areas		658.1		805.0		731.9		133.1		1031.1		166.0		171.5		3696.7
Total		1396.0		1520.3		1156.7		391.1		1916.6		343.4		400.2		7124.3

Note: 1 km^2 = 0.386 $mile^2$.

Figure 1. Office sites initiated in Atlanta metropolitan area between 1970 and 1976.

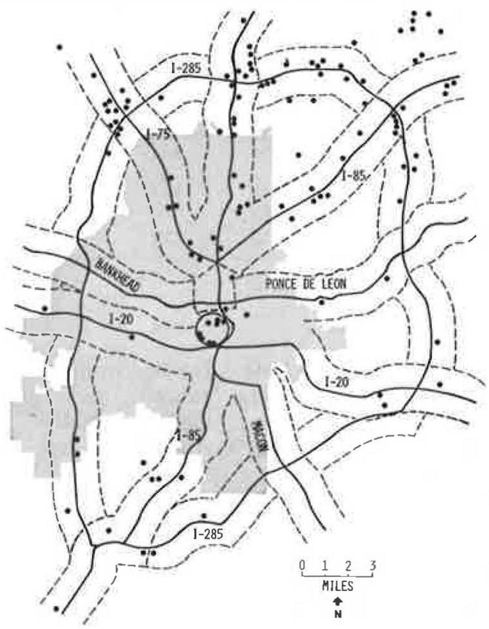


Figure 2. Office sites initiated in Dallas metropolitan area between 1970 and 1976.

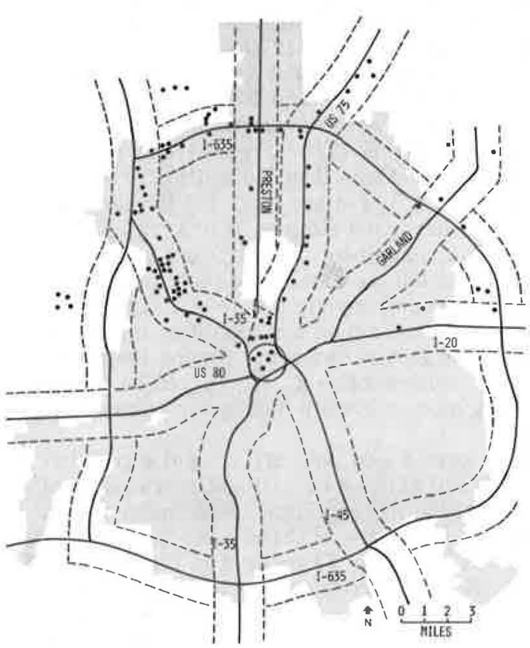


Figure 3. Office sites initiated in Denver metropolitan area between 1970 and 1976.

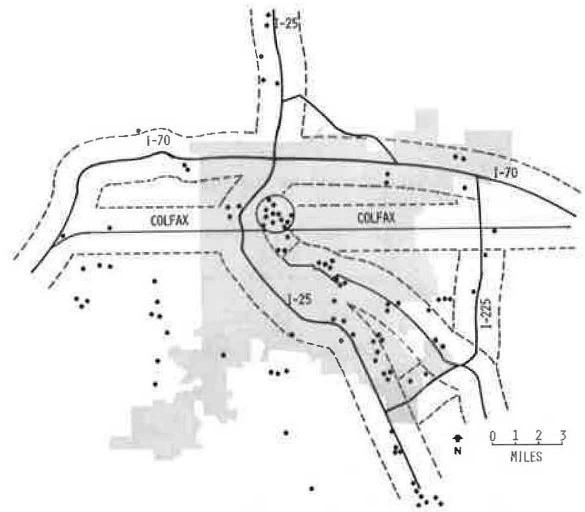
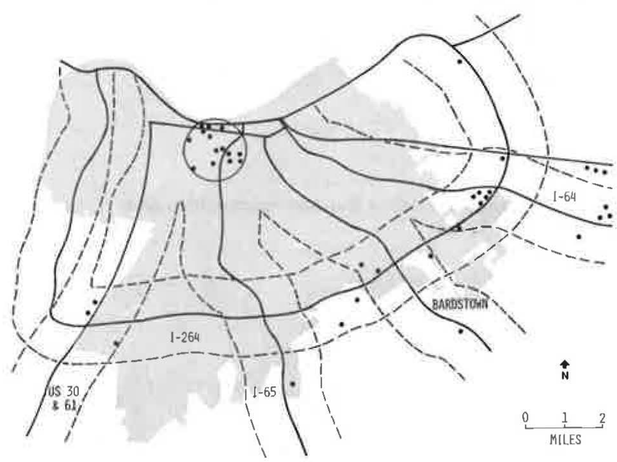


Figure 4. Office sites initiated in Louisville metropolitan area between 1970 and 1976.



core and the circumferential, and (c) the existence of a comprehensive and accurate inventory of office sites.

An attempt was made to provide as good a regional distribution as possible of metropolitan areas to be studied. Selecting them from diverse geographical areas allowed for the inclusion of metropolitan areas of different ages with different regional functions and ties. Their distribution represents most of the large regions of the United States: San Jose represents the

Figure 5. Office sites initiated in Minneapolis-St. Paul metropolitan area between 1970 and 1976.

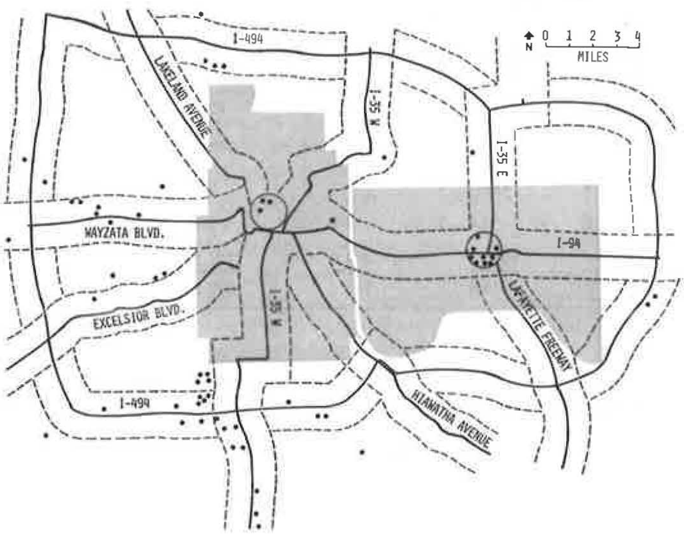


Figure 6. Office sites initiated in Omaha metropolitan area between 1970 and 1976.

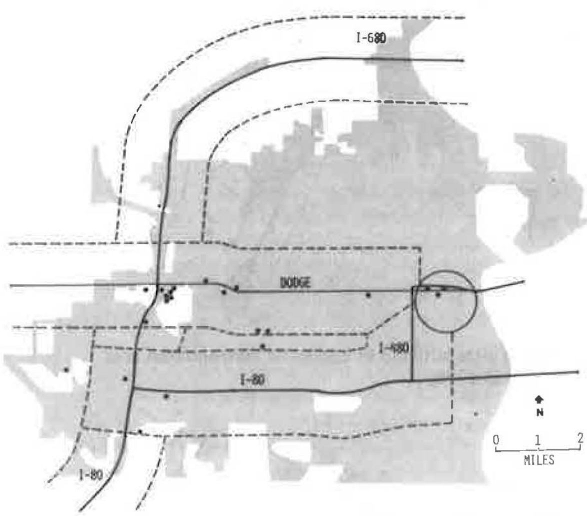


Figure 7. Office sites initiated in San Jose metropolitan area between 1970 and 1976.

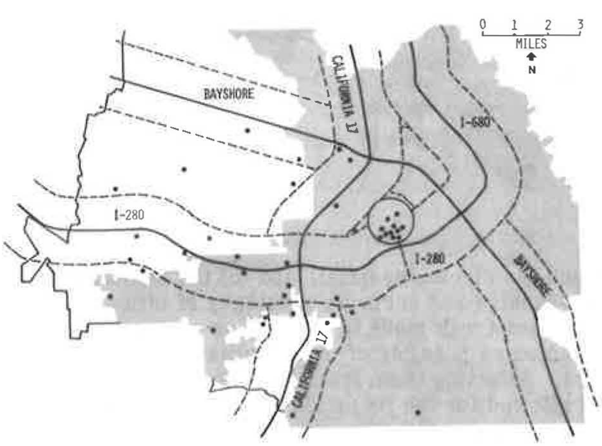


Table 2. Historical growth of office sites.

Metropolitan Area	Number of Sites: Pre-1970	1970-1976	1976 Total	1970-1976 Growth as Percentage of Pre-1970 Sites
Atlanta	119	118	237	99.2
Dallas	120	102	222	85.0
Denver	68	98	166	144.1
Louisville	33	39	72	118.8
Minneapolis-St. Paul	120	60	180	50.0
Omaha	44	22	66	50.0
San Jose	24	41	65	170.8
Total	528	480	1008	90.9

Table 3. Historical growth of gross square meters of office development.

Metropolitan Area	Gross Square Meters (000s): Pre-1970	1970-1976	1976 Total	1970-1976 Growth as Percentage of Pre-1970 Gross Square Meters
Atlanta	1791	1623	3 414	90.6
Dallas	1908	1611	3 519	84.4
Denver	541	1023	1 564	189.1
Louisville	269	409	677	152.1
Minneapolis-St. Paul	1674	721	2 395	43.1
Omaha	496	163	659	32.8
San Jose	139	265	404	189.9
Total	6818	5815	12 632	85.3

Note: 1 m^2 = 10.76 ft^2.

West Coast, Denver the West, Dallas the Southwest, Omaha and Minneapolis-St. Paul the Midwest, and Louisville and Atlanta the Southeast. Only the traditionally industrial and commercial Northeast—where most of the cities are old and well built up and there is little space for office site development between the core and the circumferential—is not represented.

INCREASE AND CENTRIFUGAL MOVEMENT OF OFFICE SITES AND GROSS AREA

The 1976 pattern of office sites in the seven metropolitan areas is a product of 7 years of growth that might well be referred to as an office "boom" in some areas. The 480 sites developed during the 1970 to 1976 period represent a more than 90 percent increase over the number of sites developed before 1970 (pre-1970 sites include only those that were developed before 1970 and that were still in place in 1976) (Figures 1 through 7 and Tables 2 and 3). More than 5.8 million gross m^2 (62.5 million gross ft^2) of space were put in place in this period; this increased the pre-1970 area by 85 percent. By 1976, San Jose, Denver, and Louisville had more than doubled the number of their pre-1970 office sites, and Atlanta nearly did so. A similar pattern held across the seven metropolitan areas for increases in gross square meters. Among the seven, only Omaha and Minneapolis-St. Paul could be described as showing only modest growth during the period from 1970 to 1976.

This 7-year period saw not only a rapid expansion but also an outward shift—a centrifugal movement—of office sites in all the metropolitan areas under study. In the aggregate, the cores of these metropolitan areas showed a modest growth of 23 percent in the number of sites and 40 percent in gross square meters (Table 4). The noncore areas, on the other hand, experienced growth rates of over 200 percent in the number of sites

Table 4. Growth in number and area of office sites in core and noncore areas between 1970 and 1976.

Metropolitan Area	Sites: Core Number	Sites: Core Increase (%)	Sites: Noncore Number	Sites: Noncore Increase (%)	Gross Square Meters: Core Number (000s)	Gross Square Meters: Core Increase (%)	Gross Square Meters: Noncore Number (000s)	Gross Square Meters: Noncore Increase (%)
Atlanta	10	13.6	108	234.8	436	41.1	1188	162.4
Dallas	11	17.8	91	193.6	407	29.2	1204	233.6
Denver	15	36.5	83	307.4	335	84.6	689	472.0
Louisville	14	53.8	25	280.0	224	103.3	184	280.7
Minneapolis-St. Paul	12	14.3	48	133.3	262	23.9	459	79.3
Omaha	3	11.5	19	105.6	43	15.2	120	56.4
San Jose	11	110.0	30	214.3	94	150.0	170	222.5
Total	76	23.6	404	207.2	1801	40.0	4014	173.5

Note: 1 m^2 = 10.76 ft^2.

Table 5. Increase in number of office sites in each type of location as percentage of total growth in metropolitan area from 1970 to 1976.

Metropolitan Area	Interstate Radials Number	Interstate Radials Percent	Non-Interstate Radials Number	Non-Interstate Radials Percent	Circumferentials Number	Circumferentials Percent	Cores and Core Extensions Number	Cores and Core Extensions Percent	Noncorridor Areas Number	Noncorridor Areas Percent	Total Number
Atlanta	47	39.8	23	19.5	25	21.2	10	8.5	13	11.0	118
Dallas	42	41.2	26	25.5	15	14.7	11	10.8	8	7.8	102
Denver	39	39.8	15	15.3	4	4.1	15	15.3	25	25.5	98
Louisville	12	30.8	7	17.9	3	7.7	14	35.9	3	7.7	39
Minneapolis-St. Paul	11	18.3	11	18.3	18	30.0	12	20.0	8	13.3	60
Omaha	3	13.6	14	63.6	0	0	3	13.6	2	9.2	22
San Jose	10	24.4	9	22.0	-	-	11	26.8	11	26.8	41
Total	164	34.2	105	21.9	65	13.5	76	15.8	70	14.6	480

Table 6. Increase in gross square meters of office development in each type of location as percentage of total growth in metropolitan area from 1970 to 1976.

Metropolitan Area	Interstate Radials Gross Square Meters (000s)	Interstate Radials Percent	Non-Interstate Radials Gross Square Meters (000s)	Non-Interstate Radials Percent	Circumferentials Gross Square Meters (000s)	Circumferentials Percent	Cores and Core Extensions Gross Square Meters (000s)	Cores and Core Extensions Percent	Noncorridor Areas Gross Square Meters (000s)	Noncorridor Areas Percent	Total Gross Square Meters (000s)	Total Percent
Atlanta	455	28.1	223	13.7	411	25.3	436	26.9	98	6.0	1623	27.9
Dallas	504	31.3	482	29.9	154	9.6	407	25.3	63	3.9	1610	27.7
Denver	387	37.8	124	12.1	28	2.7	335	32.7	150	14.7	1024	17.6
Louisville	105	25.7	24	6.0	29	7.0	224	54.8	26	6.5	408	7.0
Minneapolis-St. Paul	97	13.4	95	13.3	178	24.6	262	36.3	90	12.4	722	12.4
Omaha	23	14.0	77	47.1	0	0	43	26.6	20	12.3	163	2.8
San Jose	69	26.1	54	20.4	-	-	94	35.6	47	17.9	264	4.6
Total	1640	28.2	1079	18.6	800	13.7	1801	31.0	494	8.5	5814	100.0

Note: 1 m^2 = 10.76 ft^2.

and more than 170 percent in gross square meters. The difference in growth rate between number of sites and gross square meters results from the fact that noncore sites tend to be smaller than those in the cores. Two areas with strong and active urban redevelopment programs—San Jose and Louisville—both more than doubled their pre-1970 square meters of office development during the 1970 to 1976 period. Nevertheless, noncore growth even in these two areas exceeded 200 percent. In every metropolitan area, the number of sites in the noncore area more than doubled in the period. This is the single most important growth rate in the metropolitan area for, regardless of the square meters involved, these new sites represent an aggregate of individualized location decisions.

CHANNELING OF CENTRIFUGAL MOVEMENT

Office site growth outside the cores was not, however, evenly distributed over the noncore areas. The largest proportion of growth in the seven metropolitan areas in the period from 1970 to 1976 occurred in Interstate radial freeway corridors (Table 5). In Atlanta, Dallas, Denver, and Louisville, Interstate radial corridors ranked first among all noncore spatial units in growth of office sites. In San Jose, the Interstate radials ranked second but the proportions of the metropolitan increase were unusually well distributed among the three noncore spatial units. This was not the situation in Omaha where the non-Interstate radial (Dodge Street) absorbed the bulk of the increase and the Interstate radial corridor was thus a distant second. Nor was it the case in Minneapolis-St. Paul where the Interstate circumferential ranked first in noncore growth and the Interstate radial corridors second.

On the basis of the increase in gross square meters, Interstate radial corridors in Atlanta, Dallas, Denver, and Louisville recapitulate the site rankings and lead all noncore spatial units in these metropolitan areas

(Table 6). The larger size of office sites in the San Jose Interstate radial corridors contributed to raising these spatial units to first ranking. Interstate radial corridors in Omaha and Minneapolis continued to lag behind the non-Interstate radial corridors and the Interstate circumferential respectively in their proportion of the total metropolitan growth in gross square meters in the 1970 to 1976 period.

ROLE OF ACCESSIBILITY FACTORS

The role of the Interstate freeway as a force that attracts office development to locate nearby can be traced through several variables usually found in industrial location theory. Primary among these is accessibility. The concept of accessibility, however, is most useful in explaining the impact of an Interstate freeway or any other link in the transportation network when it is differentiated rather than generalized into a single measure

At a minimum, the accessibility of a site can be viewed from several different levels. Macroaccessibility relates the office development site to other important activity nodes within the metropolitan area. These nodes should be differentiated. Accessibility to the CBD or core—the traditional center of office and government functions—must be considered. Accessibility of the site to potential employees (i.e., white-collar workers) should also be examined, especially since labor supply is a prominent variable in industrial location models. The realities of office location decision making also require an examination of the relation between the site selected and the residences of the decision makers and other executives. Accessibility to clients (or markets) is another standard factor in industrial location models. But it should be noted that offices are not an undifferentiated mass and that the location of clients may be of no concern to the purely administrative (or headquarters) office but of considerable importance to offices oriented toward a local market because of "sales" activities (e.g., real estate, law, and insurance) (1).

A second level of accessibility is mesoaccessibility, which refers to the relation between the office development site and the freeway. The speed and ease of entry to and exit from the freeway system can be an important factor. Development is much more likely at freeway intersections than between exits, and the data presented earlier in this paper indicate that office development is generally more likely to occur within 1.6 km (1 mile) of a freeway than farther away. An example of the effect of mesoaccessibility is the attractiveness of Interstate freeways for office development in Dallas, which is strongly influenced by the extensive use of frontage or service roads that parallel the freeway. A negative example may be cited in San Jose where an office building adjacent to the freeway but with limited access to freeway drivers because a nearby exit is provided only for eastbound traffic has had a high rate of vacancy for several years.

The third level of accessibility is microaccessibility, which refers to the ease of entry to and exit from the office development and includes such factors as the number and location of driveways and parking facilities. This factor is almost totally controllable by the developer of the site and is unrelated to the location of freeways or other major links in the transportation network. But it may be involved in the decision making of a potential renter or user of office space and therefore may contribute to the attractiveness of the specific development. This in turn may contribute to the broad pattern of office development location because the speed at which a development is occupied influences other investors and developers who may not adequately assess the reasons for success or failure.

Accessibility to White-Collar Workers

Accessibility to the residences of white-collar office workers is highly related to the attractiveness of a freeway corridor for office development. In general, office development occurs in the direction of the predominant concentration of white-collar workers. For instance, the largest concentrations of white-collar workers in the metropolitan Louisville area occur in the eastern portions near I-64E; this freeway is also marked by a large proportion of recent office development. Similarly, in the Dallas area, the white-collar population is concentrated north of the CBD and recent population trends suggest a continuation of this trend; not unexpectedly, therefore, all of the office development since 1970 has been north of, or inside, the CBD. The result is that I-35E north of the CBD exhibits large growth in this decade while the continuation of this freeway south of the CBD shows no attraction for new development (and relatively little development before 1970).

The pattern is repeated in San Jose where the highest white-collar accessibility occurs in the western portion of the study area served by I-280, which in turn is highly attractive to office developments. In contrast, the continuation of I-280 east of the CBD, designated as I-680, does not serve white-collar workers and does not have any large office developments. Atlanta's concentration of white-collar workers is north of the CBD as is most of its office development.

Accessibility to Executives

Even more important than accessibility for secretaries and clerks is accessibility for their bosses, who are the decision makers on office location. The importance of accessibility of office developments to the residences of location decision makers has been noted by analysts and practitioners alike. For instance, Quante (2, p. 104) has concluded that

> The most important consideration in headquarter relocation is usually an interest in reducing the commuting burden of senior executives. Indeed, this factor is so important that many headquarters choose locations close to the residences of top management.

Location theories stress the economic rationality of maximizing profit and minimizing costs and may exclude this factor as subjective and exogenous. But Quante argues that corporations that place a high value on the well-being of their senior executives are making a rational economic decision.

Manners (3, p. 96) has observed that

> The reasons for the growth of suburban office activities are not difficult to find. Above all else, it is the transportation convenience of suburban locations which has been the most influential with office managers and developers alike. A shorter journey to work for at least the key executives, the ability to use automobiles with free or low-cost parking at the office . . . are all decisive in the locational trend.

A Dallas leasing agent, expounding on an "intercept theory," explained, "This theory is nothing more than the idea that if you can put a building close to where the decision makers live, you will lease your space" (4, p. 31). Dallas provides some additional data to support this contention. Although northeast Dallas and neighboring Garland have some large concentrations of white-collar workers, corporate managers are more likely to live northwest of the CBD, and this is where new office development has been concentrated.

This factor becomes especially important for office location decisions because traditional industrial location theory, with its emphasis on labor, raw materials, and marketing costs, is not applicable to offices. Their "main products—decisions—are intangible, and most of their inputs are unquantifiable" (2, p. 4).

In summary, accessibility of office sites to white-collar workers, especially top executives, is an important factor in determining the location of recent office developments. The freeway, therefore, contributed to the suburbanization of office space by first contributing to the suburbanization of residences; once the executive lived in the suburbs and commuted to the CBD, he or she began to think of suburbanizing the place of work as well.

Accessibility to the Core

The traditional site for office buildings and government centers and auxiliary services has been the CBD or core of a city. This has been declining in recent years for a number of reasons. Certainly, one of these reasons is that developments away from the core may still enjoy excellent access to it because of improvements in the transportation network. The completion (or near completion) of the freeway system, with radials that extend from the core and link into a circumferential freeway, has given outlying areas excellent access to the business and cultural attractions that remain in the core. The decline of the core can also be traced to the physical decline of the area and the physical and social decline of surrounding neighborhoods. Another factor that contributes to the relative decline of the core as a site for offices has been an improvement of the communications system that has resulted in a decreased need for face-to-face communication. In addition, the increasing size and complexity of modern businesses have resulted in corporations increasingly relying on their own staffs for financial, legal, and other services rather than purchasing them from nearby firms.

More firms therefore find that they do not need the amenities of the city core and so are willing to move farther from it. In fact, in Dallas in 1974 a concentric zone 6.4 to 8 km (4 to 5 miles) from the core contained 13 percent of the office buildings and 12 percent of the gross floor area, but the zone only 1.6 to 3.2 km (1 to 2 miles) from the core had only 7 percent of the buildings and 3 percent of the office space. A zone still farther from the CBD [8 to 16 km (5 to 10 miles) from the center] contained more than one-fourth (28 percent) of all office buildings and almost one-fifth (19 percent) of the gross floor area in Dallas County (5).

In Louisville, no office site on the I-64 radial is closer than 11.3 km (7 miles) to the core, and there is only one office development between the core and the core side of the 3.2-km (2-mile) circumferential freeway corridor. Office developments 16 km (10 miles) east of this core but near the radial freeway have been successful, and local developers expect still more development 4.8 km (3 miles) farther out when a new outer circumferential freeway intersects with the radial.

Similarly, in Minneapolis-St. Paul the nearest new office developments not in the cores are 13 km (8 miles) out, and I-94, which links the two cores, has not had any office development during the 1970s. The next office boom is expected to occur 26 km (16 miles) south of the Minneapolis core where I-35E and I-35W will merge.

The circumferential freeways—or, more accurately, portions of them—are often more attractive to new office developments than the radials that extend into the core (the heaviest concentration usually occurs near the intersections of a radial freeway and the circumferential freeway).

In summary, distance from the core is of virtually no importance in the location of office development. Access to the core, however, is still important; office developers and rental agents still boast "only minutes from downtown" by the freeway. But the additional 5 to 10 min spent as a result of a location farther away is easily tolerated, especially as these trips to the core become rarer.

COSTS

The second broad category of variables that is potentially useful in explaining the location patterns of office development is dollar costs, some of which are translatable from the accessibility measures just noted. Several types of costs are theoretically relevant for the office-location decision maker. For the developer, the price of land and construction may be crucial, and these costs are in turn passed on to the user of the office space. Taxes are another cost factor frequently relied on as an explanation for differentials in the rate of economic growth. Labor cost is the final theoretical cost category; its usefulness in explaining intrametropolitan location decisions is quite limited, however, since wage rates do not vary appreciably within a metropolitan labor market.

Tax Differentials

Theoretically, any cost differential should act as a factor that attracts development to the less expensive site. Some business people point to higher tax rates to explain why they leave one area for another. But these tax differentials are generally relatively small. For instance, in Dallas a $1 000 000 office building would pay $10 463 in real property taxes to the city; in University Park, an enclave surrounded by Dallas, the same building would pay $5720 in city real property taxes. This $4743 difference may seem large but, when it is proportioned over the typical size for a $1 000 000 building, the difference is approximately $1.08/m^2 ($0.10/ft^2) of floor area per year. This is less than the $0.50 variation in cleaning service costs experienced by various managers of office buildings in the Dallas area [according to data supplied by the Dallas Association of Building Owners and Managers in September 1976, the variation in cleaning service costs was more than $5.38/m^2 ($0.50/ft^2) even when the most extreme rate at each end of the cost range was ignored]. This differential is only a small proportion of the average annual rental rate of $69.06/m^2 ($6.42/ft^2) and an even smaller proportion of the total costs of operating an office when labor costs, which can be as high as $430 to $645/year/m^2 ($40 to $60/year/ft^2) and represent approximately 85 percent of total expenses (3, p. 98), are included.

Not only is the difference in tax rate between cities usually small but it may also be less significant than intercity variations in assessment practice. [Although tax differentials are usually relatively small, two of the metropolitan areas studied in this report (Minneapolis-St. Paul and Atlanta) had tax rates two to three times higher in the central city than in some of the outlying suburbs. Developers in Minneapolis-St. Paul were especially strong in their claims that higher taxes in the two central cities were an important factor in the suburbanization of office space in that metropolitan area despite the provision of the Metropolitan Development Act of 1971, which redistributes a small portion of commercial property taxes to all cities in the metropolitan area.] A Denver developer added that differences in the "sophistication" of cities in the development process may be more important; a city such as Denver may be better prepared than some of the satellite communities to aid a developer by cutting time delays in granting permits and thus reducing the developer's front-end costs.

It should also be noted in any evaluation of the impact of tax (or other cost) differentials on office development patterns that office occupancy rates are more sensitive to quality considerations than to cost considerations (3, p. 98). Buildings with low rental rates are often those with high vacancy rates because the building is not considered prime space.

Price of Land

The relation of the price of land to its attractiveness for office development is not a simple one. At a minimum, as the land becomes more attractive (e.g., its accessibility is improved through improvements to the transportation network), its price increases.

The price of land may not be a critical factor in development because the higher price of a land parcel can be compensated for through more intensive development. Thus, the core in the study cities where land costs are as high as \$269 to \$807/m^2 (\$25 to \$75/ft^2) is still a viable site for office development if high-rise development is substituted for garden-type development.

But the lower price for land farther away from the core enables the development of larger parcels that can provide ample space for free parking. This is an important inducement for firms currently located in the CBD. One observer sees it as the equivalent of a \$30/month salary increase (4, pp. 31-32).

The use of larger parcels of land also permits the use of garden development or low-rise construction, which is cheaper. Cheaper land and cheaper construction combine to contribute to cheaper office space than can be found in comparably aged buildings in the core.

In summary, if all other factors are equal, cheaper land will attract office development. But all other factors are rarely equal. Therefore, one must conclude that, within limits, the price of land is not a determinant of where offices are developed.

Availability of Land

Another variable that may be considered a necessary condition before development can occur is a supply of available land. An analysis of the impact of freeways on the location of office development should examine this variable.

Freeways play an important role in making land available for development by providing access to it for potential users in the metropolitan area. An analysis of the location patterns of new office development must consider the role of available land in shaping those patterns. It is possible, for instance, for one freeway to pass through vacant land that, when combined with improved accessibility, attracts new development to the area while another freeway is routed through an already-developed area that may serve to inhibit new development despite the added accessibility. This is one explanation offered for the extensive office development along I-35W and the southwestern portion of I-494 in Minneapolis and the virtual lack of new development along I-94 linking Minneapolis and St. Paul.

An examination of vacant land in the seven cities studied leads to the conclusion that available land may be a necessary condition but is not sufficient to attract development. For example, there are large tracts of vacant land along the southern terminus of I-35 in Dallas, and yet the new development is along the portion of I-35 north of the CBD (Stemmons Freeway). Similarly, there is more vacant land near the southern leg of the I-635 circumferential than near its northern leg, and yet the latter is considered the "hot" area for development in the Dallas metropolitan area.

But even the conclusion that available land is a necessary condition for office development must be tempered by raising the question of what constitutes available land. The concept cannot be limited to vacant lots or larger parcels because much of the new development in suburban areas occurs on land converted from agricultural use (e.g., much of the office development in San Jose is in former fruit orchards). If land is devoted to another land use—whether it be agricultural, residential, or commercial—it may still be considered available for office development if the cost of purchasing and clearing it is no higher than the price of vacant land elsewhere and if zoning and other land-use restrictions permit it.

The availability of land is therefore a function of price and zoning and not of current land use. This is not to say that adjacent land use is unimportant. The lack of development along much of I-80 in Omaha is attributable to the attraction of industrial and warehousing land uses to this area because of the Union Pacific railroad tracks that are adjacent to and parallel with the freeway. Similarly, the pattern of office development locations shown in Figures 1 through 7 indicates some agglomeration of similar units since it is rare for an office site to be isolated from other office developments. The availability of land may also be a function of the size of the parcel; outlying land is more likely to be available in large parcels whereas already-developed land may be divided into smaller parcels spread over broader ownership, which makes the aggregation of a sufficiently large land package a difficult process.

It should be noted that the importance of zoning and other land-use restrictions (e.g., building height or setbacks) will vary with the ease with which they may be amended in any city. Increased concern for the environment and increased citizen participation have made variances more difficult to acquire, especially if residential land is affected.

CONCLUSIONS

The data for the seven cities studied indicated that greater growth of office developments occurred outside the downtown core than in it. The greatest proportion of office sites developed in the 1970 to 1976 period occurred in Interstate radial corridors. Among the most significant factors that influenced the pattern of new office sites was the accessibility of the office location to residences of white-collar workers, especially those of the decision makers who determine office location. Other factors—distance to the downtown core, metropolitan tax differentials, and availability and price of land—were much less significant.

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Neighborhood Quality-of-Life Indicator Model for Highway Impact Assessment

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Research was undertaken to evaluate and test the relevance and usefulness of a quality-of-life indicator model for evaluating the effect of highway construction on a neighborhood. The model was tested by using data collected for six study areas (and for approximately the same number of control areas) in each of four selected metropolitan areas (Indianapolis, Kansas City, Omaha, and St. Louis) between 1960 and 1970. The quality-of-life production model, which essentially consists of two production functions that express the changes in the quality of life of study and control areas respectively in response to the changes in the component indicators as a result of highway construction and other exogenous changes, did reveal promising results from field survey data. Neighborhood quality of life was about 3 to 6 percent better in the study areas with highway construction than in the control areas without highway construction. The changes or improvements resulting from highway construction are statistically significant and are different from zero.

Interest in the problems of evaluating impacts on urban neighborhoods of transportation development in general and highway construction in particular has been growing considerably. Recently, as pointed out by Wachs (1), the issues related to the impact of transportation systems have become more compelling than issues related simply to the balance between supply of and demand for transportation services. Americans are becoming more concerned about so-called "concomitant outputs," such as the tangible and intangible effects of the system on society and the environment (e.g., air pollution, noise, land use, urban sprawl, community life-style, and neighborhood cohesion), than about "performance outputs," such as changes in travel times, volume, costs, and other objectives of the transportation system.

How can the relations between the amount and distribution of travel and the social, economic, political, and environmental impacts of transportation facilities and systems be identified, measured, and evaluated? What specific changes can be recommended so that the performance outputs can be maximized and the adverse concomitant outputs minimized? What research is needed that would contribute to efficient and optimal decisions regarding the provision of transportation facilities and services in both the short and long run in urban and rural areas? Answers to these questions are of critical importance because any intelligent transportation decision requires not only a comprehensive plan with detailed construction engineering and architectural design but also a variety of assessments of the potential impacts of the transportation project on socioeconomic, environmental, and ecological receptors.

In 1962, Congress passed legislation that requires that all future freeways constructed in urban areas be based on "comprehensive planning for the entire metropolitan area." Such plans were to include consideration of the total transportation needs of the area and were to be based on anticipated long-range land-use plans for the region. Thus, concerns other than just transportation issues were introduced into the decision-making process (2). For example, one additional question regarding freeway construction that has been raised is whether the benefits derived from the particular freeway are greater than the costs—direct or indirect, tangible or intangible, social or private—associated with the construction of that freeway.

Generally, the demand for highway construction is based on the need for upgrading transportation services, which are actually joint products that combine safety, capacity, accessibility, and quality of service. The most immediate and direct effects of the construction are the most measurable, and probably the most predictable, changes brought about by the investment in road building. These are called direct or first-order impacts and are characterized as changes in input, performance outputs, and concomitant outputs.

The indirect or second-order impacts arise when the direct impacts are viewed in concert with the environment within which they take place. For instance, as a consequence of highway construction, people adjust their travel habits and activity patterns to benefit from the performance outputs of the newly constructed highway. Mobility may be improved and travel time decreased. Land and property values may increase because of proximity and better access to the highway or may decrease because of a high level of pollution, noise, and community disturbance.

Tertiary or third-order impacts are further repercussions entirely within the physical and institutional environments of the constructed highway that result from, but are not directly associated with, the direct impacts. However, they may occur as intended or concomitant responses to the indirect impacts. Improved community education programs and activities brought about by greater local revenues as a result of increased property values illustrate a potential tertiary beneficial impact of highway construction. The development of programs to protect the environment, to promote community beautification, and to encourage citizen involvement and participation in total community planning is another example of a third-order impact.

All positive and negative aspects of the neighborhood effects of highway construction are critical to the ultimate highway location and investment decision, but they have been neither well identified conceptually nor extensively measured empirically. If the impacts of a highway on a neighborhood or a community can be identified and measured, plans can be made to minimize the adverse effects and maximize the beneficial results so that overall social well-being is enhanced in the communities through which highways are built. Thus, techniques to identify and estimate community effects of freeways are needed in order to make efficient location decisions. This need is recognized by the Federal Highway Administration; in fact, several research projects aimed at developing predictive models specifically for that need have been completed (3, 4, 5, 6, 7, 8).

The primary objective of this paper is to evaluate empirically and to test the relevance and usefulness of a quality-of-life indicator model for neighborhood impact assessment. Empirical results on changes in neighborhood quality of life attributable to highway construction are derived and discussed by using four case studies.

TRANSPORT-VARIANT QUALITY-OF-LIFE PRODUCTION MODEL

Quality of life (QOL) is a new name for an old notion. It is a subjective term for the well-being of people and the environment in which they live. For any individual, QOL expresses that set of "wants"—physical (PH) and psychological (PS)—which, when taken together, make the individual happy or satisfied. The concept of quality of life varies not only from person to person but also from place to place and from time to time. However, recognition of these difficulties should not deter efforts to define and measure community quality of life and to do so in a manner that has some meaning in the decision matrix associated with comprehensive planning for highway development. Since most psychological inputs to quality of life can be neither quantified nor generalized, an empirical measure of the level of quality of life people enjoy requires that the psychological attributes be held constant, as proposed by Liu (9, 10, 11); i.e.,

$$QOL_{jt} = f(PH_{jt}/PS_{jt}) \quad (1)$$

Let H denote highway construction and EX represent all other exogenous changes that affect components of QOL. The neighborhood quality-of-life indicator model can be described as follows:

$$QOL^s_{jt} = g\,[EC(H, EX), ED(H,EX), SE(H,EX), MA(H,EX)] \quad (2)$$

$$QOL^c_{jt} = h\,[EC(EX), ED(EX), SE(EX), MA(EX)] \quad (3)$$

where j and t denote the jth neighborhood and time period t and s and c denote the study and control areas. The variables EC, ED, SE, and MA represent respectively the economic, education, social and environmental, and mobility and accessibility attributes included in the model as the major impacted areas.

The effect of highway construction and other concomitant exogenous changes on neighborhood quality of life can be described by

$$\begin{aligned} dQOL^s = {} & (\partial g/\partial EC)\,[(\partial EC/\partial H)dH + (\partial EG/\partial EX)dEX] \\ & + (\partial g/\partial ED)\,[(\partial ED/\partial H)dH + (\partial ED/\partial EX)dEX] \\ & + (\partial g/\partial SE)\,[(\partial SE/\partial H)H + (\partial SE/\partial EX)dEX] \\ & + (\partial g/\partial MA)\,[(\partial MA/\partial H)dH + (\partial MA/\partial EX)dEX] \end{aligned} \quad (4)$$

Note that the signs of the partial derivatives of QOL with respect to the four components are all positive, whereas the signs of the partial derivatives of the four components with respect to H and EX are ambiguous a priori. In light of this, the net effect of highway construction on neighborhood quality of life is ambiguous a priori and should be determined by empirical estimation. The quantitative effects of highway construction on the physical quality of life of a neighborhood may be additively measured.

In the case of control areas that are assumed not to be affected by highway construction, the first term in each of the four brackets on the right-hand side of the last equation vanishes. Thus,

$$\begin{aligned} dQOL^c = {} & [(\partial g/\partial EC)(dEC/dEX) + (\partial g/\partial ED)(dED/dEX) \\ & + (\partial g/\partial SE)(dSE/dEX) + (\partial g/\partial MA)(dMA/DEX)]\, dEX \end{aligned} \quad (5)$$

One is able to draw inferences regarding the effect of a highway on a neighborhood by comparing the relative magnitudes of $dQOL^s$ and $dQOL^c$. Specifically, if $dQOL^s$ is greater (or smaller) than $dQOL^c$, highway construction is likely to be conducive (or detrimental) to the physical quality of life of a neighborhood.

More than 30 factors were originally selected to represent the four physical segments of neighborhood quality of life most affected by highway construction—i.e., economic, education, social and environmental, and mobility and accessibility. The factors were selected on the basis of the following criteria for social indicators:

1. Commonality—They should be sufficiently universal so that the fundamental principles would generally be agreed on by and apply to the majority of people in the neighborhood, i.e., a fairly good representation of the value concept.
2. Simplicity—They should be commonly understood and have a bearing on policy that could be realistically and efficiently identified, measured, and implemented.
3. Adaptability—They should be flexible enough to account for any variations in life-style input over space and time and easily adaptable to changes in values perceived by neighborhood residents in a dynamic society.
4. Neutrality—They should be neutral as to unit of measurement, open to verification according to a recognized scientific approach, and capable of being updated with new data and new scale.
5. Utility—They should be indicative, meaningful, and useful to public and private decision makers.

However, because of data problems, only 21 variables were actually used in the model for final impact assessment. Table 1 gives the variables selected in the four objective components of quality-of-life production and the expected individual variable effect.

Theoretically the four components are assumed to be independent of each other, and the QOL level should be viewed strictly as a stock variable in that it reflects the degree of human satisfaction at a particular point in time given the quantity of quality inputs possessed. In practice, some of the assumptions must be relaxed; e.g., the QOL output is usually defined over a period of time and hence is a flow variable. Since the factors of both flow and stock variables are relevant for evaluating social well-being, the actual calculation of QOL indicators involves variables characterized by both stock and flow attributes. Furthermore, the QOL model developed on an individual and personal basis is used to describe the entire neighborhood on the assumption that individuals in the neighborhood are more or less homogeneous in their socioeconomic backgrounds and utility considerations.

IMPACT OF HIGHWAY CONSTRUCTION ON NEIGHBORHOOD QUALITY OF LIFE

The model used here is in an additive linear form rather than a nonlinear approach suggested by Liu (11). Raw data on each variable were first standardized and transformed into the conventional Z scores so that the mean

Table 1. Components and factor effects of neighborhood quality of life.

Component	Factor Effect
Economic	
Individual economic well-being	
Median family income	+
Wealth	
Percentage of owner-occupied housing units	+
Percentage of households with no automobiles available	-
Median value of owner-occupied, single-family housing units	+
Community economic health	
Percentage of families with income below poverty level	-
Percentage of families with income below poverty level or greater than $15 000	-
Unemployment rate	-
Land value[a]	
Commercial and industrial	+
Undeveloped	+
Education	
Median school years completed by persons 25 years old and over	+
Percentage of persons 25 years old and over who completed 4 years of high school or more	+
Percentage of persons 25 years old and over who completed 4 years of college or more	+
Percentage of population aged 3 to 34 enrolled in schools	+
Percentage change in elementary school enrollment[a]	+
Social and environmental	
Individual conditions	
Existing opportunity for self-support	
Labor force participation rate	+
Unemployment rate	-
Percentage of workers working in their county of residence	+
Community living conditions	
Percentage of families with income below poverty level	-
Percentage of housing units that lack some or all plumbing facilities	-
Percentage of occupied housing units with 1.01 or more persons per room	-
Percentage of workers who use public transportation	+
Amount (in unit of area) of parks and recreation areas per 1000 population[a]	+
Crime rate[a]	-
Population density[a]	-
Mobility and accessibility	
Mobility	
Percentage of persons who have resided in same house for 5 years	-
Percentage of households with no automobiles available	-
Percentage of time saved in traveling to city hall	+
Housing segregation index[a]	-
Accessibility[a]	
Number of retail establishments built since 1960 (per 1000 population)	+
Number of gas stations built since 1960 (per 1000 population)	+
Hospitals built since 1960 (per 1000 population)	+
Schools built since 1960 (per 1000 population)	+
Parks and recreational areas developed since 1960 (per 1000 population)	+
New housing starts (per 1000 population)	+
Property crime rates (per 1000 population)	-
Traffic count in the busiest intersections in the tract	-

[a]Not included in the study because of data deficiency.

of the Z scores became 0 and its standard deviation became 1.0. The basic reason for this standardization is to eliminate the units of measurement among different variables so that they can be neutral and further operated on by addition or subtraction, dependent only on the direction of those variables toward the explanation of the variations in the quality of life. For observation i on any variable j, the standardized score (Z_{ij}) is measured by

$$Z_{ij} = (X_{ij} - \bar{X}_j)/s_j \qquad (6)$$

where

X_{ij} = original value that variable j takes for observation i,
$\bar{X}_j$ = mean value of all observations for variable j, and
S_j = standard deviation of variable j.

An equal weighting scheme was applied to the variables at the same level—subcategory, indicator category, and QOL component—for simplification as well as future variation in methodology. A factor analysis could result in different weights for the variables used. However, it is then difficult if not totally impossible to interpret the results and hence to make specific policy suggestions with respect to the specific variables or determinants included in the model.

In order to avoid the influence of any variable taking on extreme value under such an equal weighting scheme, all Z scores were also converted into an ordinal point scale that ranged from 1 to 5; the lowest 20.0 percentile was assigned 1, the next 2, and so on until the highest 20.0 percentile was assigned 5. The basic justification for this ordinal scale transformation is that the overall index construction is based on the additive method, which should generally be neither significantly pulled up by the extreme high values of the Z scores on certain variables nor substantially pushed down by the extreme low values of the Z scores on certain other variables.

Data for all variables given in Table 1 were collected for the 24 study neighborhood areas and the 21 control neighborhood areas in four standard metropolitan statistical areas (SMSAs)—Kansas City, Indianapolis, Omaha, and St. Louis. The composite QOL indicators were also computed according to the methodology described above.

The following criteria were the major ones used in selecting the study areas:

1. The study area had a highway that opened during the 1960s.
2. The selected census tract (the basic unit for impact assessment) had a population between 2500 and 10 000 in 1960.
3. Within the population size range, at least one tract each was selected to represent the small, medium, and large neighborhoods under study.

The study areas included census tracts 3203, 3603, 3604, 3613, 3614, 3903 in Indianapolis; 35.01, 36.01, 102.02. 105, 107.02, and 121 in Kansas City; 32, 38, 39, 68, 69, and 70 in Omaha; and 2150.01, 2177.01, 2201, 2206.01, 2212.02, and 2213.01 in St. Louis. The census tract was used as the basic unit for impact assessment because it offered the most readily available socioeconomic data required in the study.

The principal criteria used in selecting the control area were the following homogeneity considerations:

1. A residential and commercial composition sim-

ilar to that of the study area;

2. Demographic characteristics by size of population similar to those of the study area;

3. Socioeconomic characteristics by median family income similar to those of the study area;

4. No freeway passing the area and a location somewhat remote from the new highway being studied.

The corresponding control neighborhoods for the four SMSAs were 3212, 3601, 3605, 3607, 3555, and 3616 in Indianapolis; 32, 118, 125, 126, and 132 in Kansas City; 21, 36, 43, 67, and 30 in Omaha; and 2151.05, 2153.01, 2208.02, 2208.03, and 2198.00 in St. Louis.

Although the changes in QOL indicators from 1960 to 1970 in both study and control neighborhoods are important and provide us with the essential information on the general welfare in each of the neighborhoods over a period of 10 years, it should be noted that the associated changes in themselves convey no message as to the net effects of a highway on any neighborhood's general welfare. The net effects of a highway may only be reflected through comparisons of the associated changes from 1960 to 1970 in the study and the control neighborhoods. Specifically, if the associated changes during the period are greater (smaller) in the study areas than in the control areas, one may conclude that highway construction does have some positive (negative) effects on neighborhood quality of life. In other words, the effects are judged by the ratio of QOL indicators in the study areas to those in the control areas [(S/C)i] over the 10-year period. The empirical results for the six selected pairs of neighborhoods in the four metropolitan areas for the QOL component and overall QOL indicators are given in Table 2.

As the results given in Table 2 show, when all six pairs of ratios were averaged, all of the four QOL components except the economic component in Omaha received a value greater than unity. This indicates that on the whole highway construction has brought about positive effects on neighborhood quality of life on a regional basis despite the fact that many neighborhood pairs of indicator ratios are less than unity. For example, highway construction had rather negative impacts on socioenvironmental considerations in Indianapolis because four of the six neighborhood pairs showed a ratio value smaller than 1.0 when study areas were compared with control areas. Similarly, unfavorable economic results were shown for Omaha, and the negative impact was such that it even surfaced to appear at the metropolitan level in the last column of Table 2.

Nevertheless, the results, however tentative they are, may still lead one to conclude that on the average the construction of a highway has improved neighborhood quality of life by about 3.0 percent in Indianapolis and St. Louis, 4.0 percent in Omaha, and 6.0 percent in Kansas City.

It should also be pointed out that the last column in Table 2 represents the major findings of this study. Lower QOL indicators could conceivably be found in the neighborhood areas than in the control areas because many factors other than highway construction could affect neighborhood quality of life. As a result, it is clear that the ratios of (S/C)i could possibly be smaller than unity in some neighborhood areas even though the null hypothesis is that highway construction generally enriches neighborhood quality of life. However, the figures in the last column of Table 2 do indicate the positive results of highway construction for the metropolitan areas as a whole. By controlling the neighborhoods without highway construction, the metropolitan average comparisons indicate the general contribution of a highway to community quality of life.

Given that there are differences in the metropolitan average comparison of study and control areas—i.e., the ratios are greater than unity—one would question whether the differences are statistically significant. In other words, are the positive effects identified for the study areas really different from those for the control areas, and are they statistically different at all from a no-effect null hypothesis? A simplified Student's t-test suggested by Sandler was performed on the basis of information shown in the last column of the table (12). The computed A-statistic for the QOL component indicators is 0.173, and for the QOL indexes it is 0.273. Both are smaller than the corresponding critical values of 0.266 and 0.324 at the 5 percent significance level for 23 and 3 degrees of freedom respectively. Thus, the null hypothesis that the mean QOL values for both control and study areas are equal is rejected. Consequently, the percentage gains in average QOL indicators given in the last column of the table are statistically sustained.

SUMMARY AND CONCLUSIONS

A transport-variant quality-of-life production model that focuses on the effect of highway construction has been developed. The model essentially consists of two QOL production functions that express the changes in the quality of life of study and control areas in response to changes in component indicators as a result of high-

Table 2. Ratios of quality-of-life indicators between study and control areas, 1960 to 1970.

SMSA	QOL Component	Neighborhood Pair (S/C)1	(S/C)2	(S/C)3	(S/C)4	(S/C)5	(S/C)6	Metropolitan Average
Indianapolis	Economic	1.06	1.27	1.02	0.72	1.05	1.13	1.04
	Mobility and accessibility	1.20	1.29	1.33	1.15	0.43	0.91	1.05
	Education	1.05	1.42	1.23	0.61	1.79	0.56	1.11
	Socioenvironmental	0.87	0.88	1.79	0.65	0.95	1.47	1.10
	Overall QOL	1.02	1.21	1.31	0.78	0.88	0.98	1.03
Kansas City	Economic	1.33	1.00	0.99	1.31	0.78	0.87	1.05
	Mobility and accessibility	2.66	2.66	0.86	1.05	1.00	0.48	1.45
	Education	0.67	1.19	1.57	0.61	0.99	1.08	1.02
	Socioenvironmental	1.23	0.75	0.96	0.88	1.02	1.19	1.01
	Overall QOL	1.36	1.24	1.05	0.94	0.93	0.86	1.06
Omaha	Economic	0.65	0.92	1.15	1.05	0.85	1.25	0.98
	Mobility and accessibility	1.17	2.10	1.99	1.03	0.80	0.74	1.31
	Education	1.14	1.08	0.92	1.00	0.94	1.00	1.01
	Socioenvironmental	0.49	1.04	1.16	1.42	1.13	1.32	1.09
	Overall QOL	0.87	1.14	1.24	1.10	0.92	1.05	1.04
St. Louis	Economic	0.54	1.31	1.04	0.96	1.01	1.19	1.01
	Mobility and accessibility	0.65	1.11	0.43	0.88	1.00	2.00	1.01
	Education	0.17	1.26	1.51	1.14	1.09	1.99	1.19
	Socioenvironmental	1.00	1.44	0.96	0.91	0.94	1.01	1.04
	Overall QOL	0.52	1.27	0.91	0.96	1.03	1.49	1.03

way construction and other exogenous changes. In other words, the effect of highway construction on the quality of life of a neighborhood is estimated by summing the effects of highway construction on the transport-related factors that form the basis for the computation of the four QOL component indicators (economic, education, social and environmental, and mobility and accessibility) and then comparing them with the QOL indicators generated simultaneously for control areas in which no new highways were opened during the study period. Specifically, the net impacts of highway construction are measured by a differential rate of change between the study areas and the control areas ($dQOL^{s}_{jt}/dQOL^{c}_{jt}$).

The quality-of-life indicator model for highway impacts on a neighborhood was tested by using data collected for six study areas and six control areas in each of four selected metropolitan areas between 1960 and 1970—Indianapolis, Kansas City, Omaha, and St. Louis. Although the usefulness of the model with regard to specification and interpretation can be questioned, empirical problems did not surface when the model was applied to the selected areas for highway impact assessment.

The major findings on the recommended QOL model are that it is indicative, specific, and capable of quantitatively evaluating impacts of highway construction both for purposes of ex ante prediction for a given condition similar to that of the study areas and ex post assessment after highway construction. The opening of highways in the four metropolitan areas did improve the quality of life of the affected neighborhoods in many ways, including enhanced economic vitality, greater mobility and better accessibility, higher educational attainment, and enriched socioenvironmental conditions. For overall quality of life, the results show that a gain of some 3.0 to 6.0 percent could be attributed to highway construction.

Nevertheless, the findings in this paper are tentative and incomplete because some important variables such as crime rates, property values, and noise and air pollution were excluded as a result of a lack of data and also because the model attempted to measure quantitatively only the physical inputs to quality of life while merely assuming the psychological inputs. It would be desirable to validate the results by means of a well-designed opinion survey among the residents in the neighborhoods being studied and compared. Furthermore, the usefulness of the QOL model and its technical approach must be generalized and confirmed by more sample applications.

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Abridgment

Applications of Variable Work Hours in the Twin Cities Metropolitan Area

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This paper describes a study conducted for the Minneapolis-St. Paul Metropolitan Transit Commission in 1976 to investigate the application of variable work hours in the Minneapolis-St. Paul metropolitan area. As a major focus of metropolitan activity, travel, and transit routes, the central business district (CBD) received primary study emphasis, but suburban applications were also considered. The specific objectives of the research were to identify (a) possible benefits with respect to transit operations, (b) the degree to which traffic congestion could be decreased, (c) any impacts on high-occupancy vehicle use, and (d) any institutional impediments to the implementation of a variable work hours strategy.

STUDY PROCEDURES

The basic study process involved (a) determining the current distribution of employee start and leave times, (b) selecting those types of employers who have the highest potential for the variation of work hours, (c) identifying employer and employee attitudes to various types of variable work hour strategies, (d) determining the impact of varying work hours on high-occupancy vehicle use, (e) determining the impact of varying work hours on transit operation, and (f) determining the impact of a variable work hours program on vehicle movement.

The bulk of the study effort was based on employer and employee surveys conducted throughout the Twin Cities metropolitan area at eight sample locations that were representative of different work situations. Fifty-five employers, jointly representing 36 000 employees, responded to the employer survey. Information obtained from these locations allowed for an assessment of areawide applications (CBD), corridor applications, and an activity-center application (industrial park). Further, it allowed for a multiemployer program assessment as well as an individual employer assessment. During the course of the study, the term "staggered work hours" was interpreted as a reference to all types of programs for varying work times, including staggered work hours, flextime, and the 4-d week. Thus, the study was not limited to the staggered work hours option alone.

SUMMARY OF PRINCIPAL FINDINGS

Existing Conditions

The study revealed that an unexpectedly high percentage of surveyed firms (up to 48 percent) were currently varying work hours in some fashion. However, employers as a whole were not receptive to changes in their current work hour schedules. Even large administrative and service employers in the Minneapolis CBD (identified on the basis of research efforts in other areas as the best candidates for a variable work hours program) did not consider themselves good candidates for a variable work hours program. However, if classified on a functional basis, only a small percentage (about 16 percent) of CBD employers clearly have "fixed" schedules that are not subject to variation.

An analysis of work start and leave times revealed a sharp morning peak (around 8:00 a.m.) in both CBDs and suburban locations (Figure 1) whereas the afternoon peak was generally not as sharp since leave times were more evenly distributed throughout the peak period. The evening peak also seems to vary in each location surveyed. For example, in the Minneapolis CBD, employee leave times are fairly evenly distributed between 3:45 and 5:15 p.m., but suburban afternoon leave times appear to peak more sharply. The afternoon CBD vehicle peak is generally greater than the employee leave times in the survey might indicate, apparently because of through traffic and the time spent in the CBD by employees who leave early for other activities. Differences in peaking characteristics must then be considered in the application of a variable work hours program.

Employee start and leave times in the Minneapolis CBD peak differently for different types of industry, demonstrating a certain degree of natural work hour staggering. For example, nearly all retail employees (90 percent) begin work after the morning peak time and leave work after the afternoon peak time. As a result, it appears that retail employment is not a major component of peak-hour traffic.

Employer Attitudes

The majority of employer respondents indicated that they would not support any areawide variable work hours program to improve transit or multioccupancy vehicle service for a number of reasons that relate to business efficiency. Employers were particularly opposed to a 4-d workweek. If hours were to be changed, the maximum acceptable range was 1 h before or after current working hours. There was greater acceptance of starting work after than before 8:00 a.m.

Employee Attitudes

Over 75 percent of the surveyed employees supported the concept of variable work hours. However, they could not agree as to the type of program or the hours. First preference was given to the 4-d week and second to flextime. Employees were opposed to changing work hours by more than 1 h in either direction (as were employers) and expressed more opposition to later than earlier hours. Major concerns regarding work hour changes were personal commitments outside current work hours and the possible creation of problems for other family members.

Perceived Impact on Mode Choice

Some shift in travel mode from bus to automobile and from car pool to driving alone is a likely result of a variable work hours program. The actual degree of the shift—short and long term—could not conclusively be drawn from the study, however.

Thirty-five percent of current employee bus riders to the Minneapolis CBD said they would shift to the automobile if they were required to start work or leave work 1 h earlier or later than their current hours. A 5 percent shift from bus to automobile might result from a 15-min work hour change. About 50 percent of employee car poolers in the Minneapolis CBD indicated that they would shift to driving alone if their work hours were changed significantly. It should be noted that these represent perceived results and thus may be overstated. In addition, the data do not account for reformation of former habits based on a new set of circumstances.

Potential Applications

The investigation of transit applications was oriented toward the reduction of bus-fleet requirements during the peak period. Currently, the peaking of transit demand, particularly in the CBD, requires a large number of buses that are all used within a short period of time (Figure 2). If work hours could be perfectly staggered, up to 39 fewer buses (6 percent of the current fleet) would be required to serve current transit demands during the peak periods. Reduction in vehicle congestion in the CBD as the result of basic staggered work hours programs was also investigated. Three examples were considered:

1. The voluntary staggering of work times for finance, insurance, real estate, and government employees (highest potential for such a program) in the Minneapolis CBD would decrease the current afternoon peak interval by 9.3 percent (approximately 502 vehicles). However, the peak is shifted from the 4:30 to 4:45 p.m. interval to the 4:45 to 5:00 p.m. interval (Figure 3). In addition, where no employees from these industry groups currently leave between 5:15 and 6:15 p.m., 8556 employees or 2663 vehicles would have to leave during this time period if staggering of work hours were introduced.

2. If an even distribution of employee leave times for all industry groups was desired, the total vehicle distribution in the downtown area would be similar to that of the voluntary staggering of selected industries for the time intervals before 5:00 p.m. (Figure 3). After 5:00 p.m., the number of trips increases significantly, and a new peak appears at the 5:15 to 5:30 p.m. interval. The new peak is only 191 vehicles less than the present peak—a generally insignificant reduction in peak-hour traffic of less than 4 percent.

3. If an even distribution of vehicle departures is desired during the peak period, an uneven distribution of employee leave times is required (Figure 3). To achieve a level of approximately 4200 vehicles leaving during each interval, approximately 19 656 persons would have to leave work at or after 6:00 p.m.—a situation that is difficult to achieve on a voluntary basis.

The employer survey indicated that certain major suburban roadway corridors, particularly US-12 west of Minneapolis, have a high degree of afternoon peaking. It would appear that traffic congestion could be decreased along this route if leave times along the corridor were evenly spread across the entire peak period.

CONCLUSIONS

The study of variable work hours resulted in the following preliminary conclusions with respect to the application of variable work hours programs in the Twin Cities metropolitan area:

1. An extensive nonvoluntary staggered work hours program has the potential to reduce the size of the bus fleet required and to reduce traffic congestion in the Twin Cities area.
2. An areawide variable work hours program in a CBD characterized by diverse activity would be extremely difficult to implement under current conditions

Figure 1. Employee arrival and departure times based on employer survey.

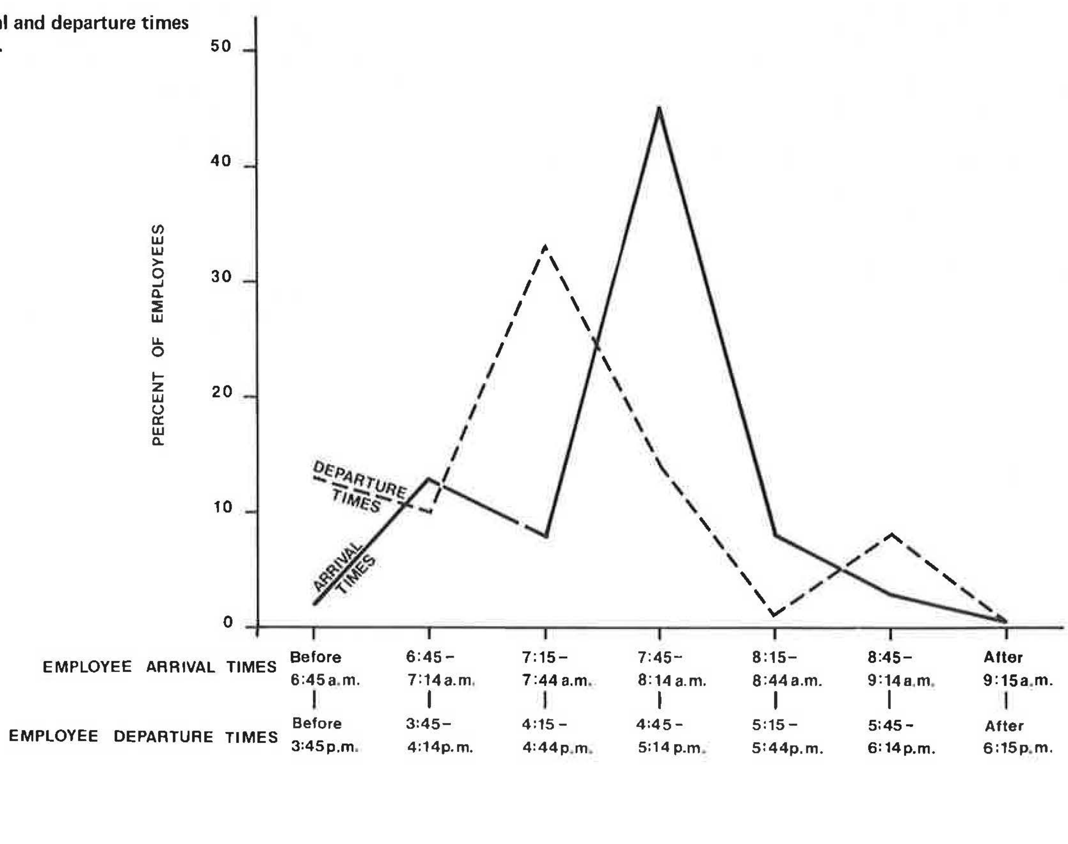


Figure 2. Distribution of bus departures from the Minneapolis CBD during afternoon peak period (4:00 to 5:00 p.m.).

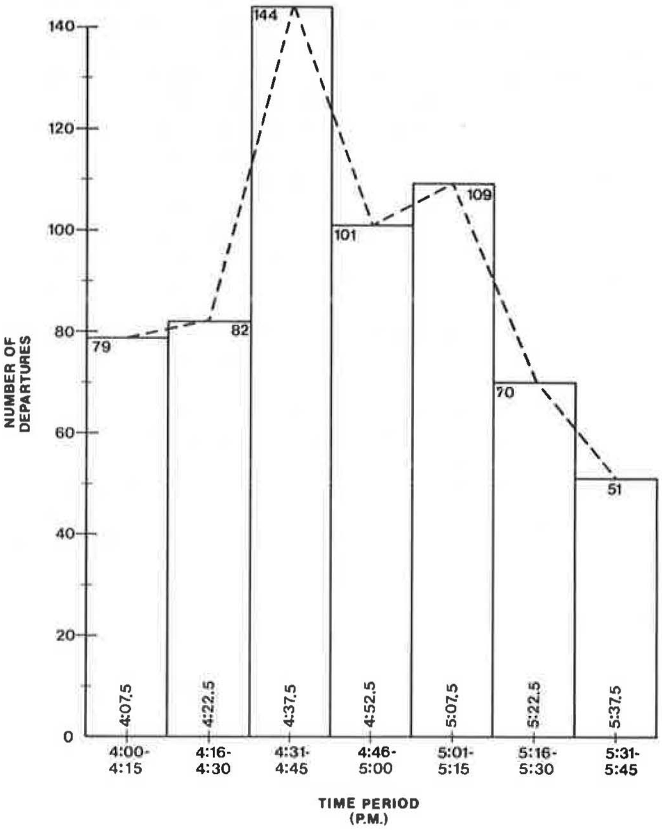
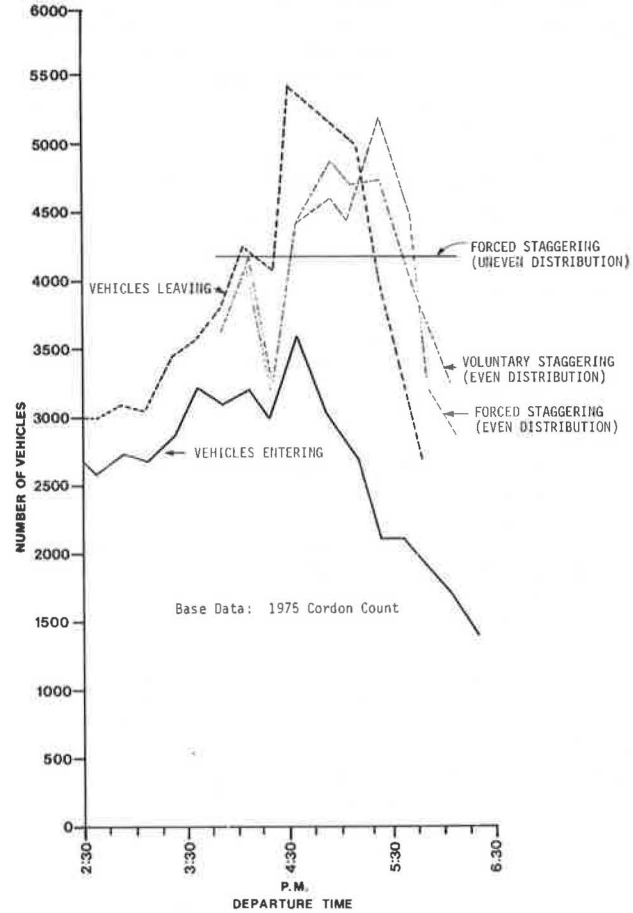


Figure 3. Effect of staggered work hours on 1975 afternoon peak period in the Minneapolis CBD.



without substantial employee incentives or government dictate. Rigid and substantial changes in work hours would be required if a variable work hours program were to be effective. Both employees and employers appear to be unwilling to accept voluntarily such drastic changes in their work hours.

3. A variable work hours program may cause a mode shift in work trip travel away from public transit, car pools, and van pools.

4. Selective, individual-employer programs of variable work hours to reduce local traffic congestion or better schedule transit service appear to have the best chance for current implementation in the Twin Cities metropolitan area.

ACKNOWLEDGMENTS

We express our gratitude to John R. Jamieson, Hugh Faville, and other members of the Twin Cities Metropolitan Area Transit Commission staff and to members of the Transit Commission's Committee on Low-Capital Alternatives for Urban Transportation Project Management and Advisory Committee for their cooperation during the conduct of the study on which this paper is based. The source for Figures 1 and 2 is Barton-Aschman Associates, Minneapolis.

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Abridgment

Analytical Process for Coupling Economic Development With Multimodal and Intermodal Transportation Improvements

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This paper summarizes part of the first year's work in a 3-year research effort undertaken by a multiuniversity research team consisting of faculty and graduate students from the University of Alabama, Arkansas State University, Auburn University, Georgia Institute of Technology, Memphis State University, Mississippi State University, the University of Missouri, the University of North Florida, and Tennessee Technological University (1). The objective of the research is to develop a quantitative technique that can identify the nature and extent of transportation improvements needed to achieve significant breakthroughs in the economic development of an underdeveloped area. The underdeveloped area of interest is a broad arc that extends from the Atlantic Coast in the vicinity of Brunswick, Georgia, and Jacksonville to the Midwest in the vicinity of Kansas City, Missouri. This arc is known as the multistate transportation corridor (2).

The focus of the work is on economic breakthroughs—transportation improvements that will provide the incremental advantage needed to support significant economic developments that would not take place without the transportation improvements. To identify breakthrough opportunities, it is necessary to consider new transportation services and ingenious intermodal combinations of existing transportation services. The need to consider complex transportation services and to identify breakthroughs separates this work from other work that depends on maintaining existing economic relations and shipping patterns (3, 4, 5).

The analytical method is built around two mathematical models: (a) a cost-based economic model and (b) a network-based intermodal transportation model. Each of these models contains unique features that were necessary to preserve the generality of the analysis. Both models use a common geographical base and deal with a common set of commodity groups. The geographical base is a set of 120 zones of varying sizes that cover the continental United States. Zones in the multistate corridor are small; each zone includes the 6 to 10 counties that make up an area planning and development commission. Outside the corridor, zones are made up of integral numbers of basic economic areas (BEAs) (6). Zones near the corridor contain a single BEA. Zones remote from the corridor may contain as many as six BEAs.

This analysis deals solely with freight movements. The universe of freight movements is divided into 53 more or less homogeneous commodity groups. These groups are somewhat more detailed than the two-digit standard industrial classification code (7) but somewhat less detailed than would be desired. Initial or "present" commodity-flow data were taken from the National Transportation Policy projections of commodity flow (8) and augmented by a variety of census data. The vicissitudes of the analysis of commodity-flow data are a suitable subject for another paper (9) and will not be treated further here. Suffice it to say that, in one manner or another, data on zone-to-zone movement were developed for each of the 53 commodity groups.

ECONOMIC MODEL

The economic model provides a representation of each industry group as it draws raw materials from available sources, uses labor and capital, and incurs costs to produce the product it ships to existing markets. A geographic representation of each commodity group was drawn from the commodity-flow data by identifying major producing zones, major market zones, and important producer-market commodity flows. Production costs and raw material requirements per megagram of product were developed for each commodity group. Production cost elements include raw material, direct labor, indirect labor, energy, capital, and taxes. The cost C_{ij} of producing commodity i at location j is

$$C_{ij} = \sum_{k=1}^{6} a_{ik} C_{ijk} \quad (1)$$

where

a_{ik} = amount of element k per unit of commodity i and
C_{ijk} = unit cost of element k for product i at location j.

All cost elements are location sensitive and had to be separately determined for each major producing zone and for each candidate zone in the multistate corridor.

Market costs $m_{ij\ell}$ were estimated for each producing zone j that supplies each market ℓ with a commodity i:

$$m_{ij\ell} = C_{ij} + \min_{m} \left\{ t^m_{ij\ell} + f_{1i}\tau^m_{ij\ell} + f_{2i}V^m_{ij\ell} \right\} \quad (2)$$

where

$t^m_{ij\ell}$ = unit transportation cost of commodity i moving from j to ℓ by mode and route m,
f_{1i} = value of a unit of travel time to commodity i,
$\tau^m_{ij\ell}$ = travel time for commodity i from j to ℓ by mode and route m,
f_{2i} = value of service dependability for commodity i, and
$V^m_{ij\ell}$ = measure of service dependability for commodity i from j to ℓ by m (equal to the variance of delivery time).

The share of the commodity i market at ℓ enjoyed by producers in zone j depends on the value of $m_{ij\ell}$ as compared with costs in market ℓ for other producers. Inasmuch as all commodities were treated in general terms, product quality was not recognized as a market determinant. A cost-market share relation was estimated for each commodity group:

$$ms^i_{j\ell} = a_i \exp(-\alpha_i \Delta H_{ij\ell}) \quad (3)$$

where

$ms^i_{j\ell}$ = share of commodity i shipped to zone ℓ from zone j,
a_i, α_i = constants for commodity i,
$\Delta H_{ij\ell} = m_{ij\ell} - m_{ik\ell}$, and
k = zone that can deliver to market ℓ at the lowest cost.

Values of a_i and α_i were determined by regression analysis based on existing commodity movements. Correlation coefficients were on the order of 0.7, not exciting values but acceptable in view of the preliminary nature of the work, the data problems, and the many embedded assumptions. The following values of a_i and α_i were obtained for eight test commodities:

Commodity	a_i	α_i
Textiles	0.068 00	-0.000 46
Apparel	0.145 49	-0.001 71
Lumber	0.117 38	-0.090 96
Furniture	0.085 42	-0.003 89
Agricultural chemicals	0.077 02	-0.003 50
Plastic products	0.131 35	-0.008 85
Machinery	0.065 58	-0.000 44
Electrical equipment	0.104 89	-0.003 09

TRANSPORTATION MODEL

The purpose of the transportation model is to generate transportation cost, time, and time-variance data for the economic model. This process is vastly complicated by the need to deal with present and prospective modes of transportation and with intermodal combinations of present and prospective modes. Aside from the problems of dimensionality associated with a multicommodity network that has 120 nodes, 400 arcs, six transportation modes, and 53 commodity groups, the major technical problems were (a) developing a mode-abstract modal-split model and (b) determining intermodal paths through the network. Both problems were partially solved, but more work is needed.

Modal-split relations were developed from the commodity-flow data by using regression analysis on the modal share distribution of existing movements. A modified logit form (10) was used in which

$$f^m_{ij\ell} = U^m_{ij\ell} \Big/ \left(\sum_{p=1}^{P} U^m_{pj\ell} \right) \quad (4)$$

where $f^m_{ij\ell}$ = modal share of mode m for commodity i moving from j to ℓ and

$$U^m_{ij\ell} = \exp(a_0 + a_1 \Delta t^m_{ij\ell} + a_2 \Delta \tau^m_{ij\ell} + a_3 \Delta V^m_{ij\ell}) \div [1 - \exp(a_0 + a_1 \Delta t^m_{ij\ell} + a_2 \Delta \tau^m_{ij\ell} + a_3 \Delta V^m_{ij\ell})] \quad (5)$$

where

$\Delta t^m_{ij\ell} = t^m_{ij\ell} - t^b_{ij\ell}$,
$\Delta \tau^m_{ij\ell} = \tau^m_{ij\ell} - \tau^b_{ij\ell}$,
$\Delta V^m_{ij\ell} = V^m_{ij\ell} - V^b_{ij\ell}$,
$t^b_{ij\ell}$, $\tau^b_{ij\ell}$, $V^b_{ij\ell}$ = attributes of the base or highest utility mode,
$a_0 = \ln(0.5)$, and
a_1, a_2, a_3 = constants.

The regression analysis focused on maintaining commodity-specific but mode-abstract values for a_1, a_2, and a_3. The results, which yielded R-values between 0.6 and 0.7, were not particularly good, but these results compare favorably with many mode-specific studies. Mode-split parameter values for the eight test commodities are given below:

Commodity	a_1	a_2	a_3
Textiles	-0.0107	-0.000 033 3	-0.000 552
Apparel	-0.0010	0	-0.000 562
Lumber	-0.0075	-0.000 041 6	-0.000 008
Furniture	-0.0087	-0.000 083 3	-0.000 166
Agricultural chemicals	-0.0072	-0.000 023 3	-0.000 062
Plastic products	-0.0045	-0.000 096 6	0
Machinery	-0.0054	-0.000 150 0	0
Electrical equipment	-0.0050	-0.000 050 0	-0.000 160

Intermodal paths are determined by establishing node impedances to reflect the cost, time, and time variance associated with intermodal transfers. By using the exponential form, the logarithms of path utilities (cost, time, and time variance) are made directly additive to produce path utility for any modal combination. Thus, the best intermodal path can be found by using a modified shortest path routine.

COMPUTER PROGRAMS

A battery of computer programs was prepared to perform the economic analysis and transportation network analysis. The principal steps are

1. Introduce existing and new arc and mode information,
2. Construct a special network numbering system to simplify multimodal analysis,
3. Obtain shortest path trees for each existing origin,
4. Load existing commodity movements,
5. Obtain shortest path trees for candidate new production zones,
6. Determine production costs for candidate zones,
7. Determine market shares for candidate zones, and
8. Update commodity movement assignments.

Currently, transportation improvements are postulated as input to the analysis. Work is under way on analytical procedures to identify potentially attractive improvement programs.

ANALYTICAL RESULTS

The analytical procedure was tested for four zones in northern Mississippi. Four transportation programs were tested: (a) the present highway, railway, and waterway networks; (b) the present networks with accessibility improvements in northern Mississippi; (c) the present networks plus accessibility improvements and highway and railway improvements along the multistate corridor; and (d) the present networks with accessibility, highway, railway, and intermodal transfer improvements.

The results of the northern Mississippi test were encouraging. With the present transportation networks, market costs for the four test zones appeared to have realistic relations with market costs for other producing zones. Economic development opportunities matched present development experience. To illustrate, the following table gives the market cost comparison for agricultural chemicals in market 85 (Cincinnati) under the present networks (base case) and under improvement alternative 4:

Source Zone	Base Case	Alternative 4
98	311	311
105	342	289
84	345	345
C 2	318	294

In the base case, multistate corridor zone 2 (Tupelo, Mississippi) looks attractive relative to other supply zones. Its market cost (HIJK) is close to that of zone 98 (New Orleans), the lowest cost producer, and substantially better than that of zone 105 (Houston). Its potential market would be approximately 14 500 Mg/year (16 000 tons/year).

Under improvement alternative 4, the relative positions of the major suppliers to the Cincinnati market would change. Zone 105 (Houston) is able to take advantage of efficient modal interchange facilities at Memphis to put together an attractive rail-water route. Corridor zone 2 would also benefit from the transportation improvements but to a lesser extent than Houston, which is the new lowest cost supplier. New Orleans (zone 98) would not benefit from the transportation improvement and would fall to third position. The potential market for corridor zone 2 (Tupelo) would increase only slightly as a result of the transportation improvement, which suggests that this improvement program would not enhance economic development opportunities in agricultural chemicals.

FUTURE WORK

A second year's research effort will be directed toward improving the analytical procedure. During the third year, the procedure will be applied to the multistate corridor.

ACKNOWLEDGMENT

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Regulatory Implications of Individual Reactions to Road Traffic Noise

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A basic problem in setting standards for acceptable levels of road traffic noise is deciding on a criterion of acceptability. The possible criteria reduce to three categories: noise impacts (i.e., activity interference and effects on health), attitudes toward noise, and actions taken to reduce the impact of noise (e.g., complaints). The rational selection of a criterion or criteria needs to be based on careful empirical analysis of two sets of relations: (a) the relations among the plausible criteria and (b) the relations between the criteria and noise measurements. The first set of relations is examined by using questionnaire data collected at 37 sites adjacent to highways in southern Ontario. The results show significant but relatively weak links between impacts and attitudes and between attitudes and actions. The analysis results (a) question the use of activity interference measures, and particularly speech interference, as a criterion for setting standards and (b) confirm the inadequacy of regulating against traffic noise on the basis of complaint action.

Faced with the problem of establishing acceptable levels of environmental noise, the difficulty immediately arises of deciding on a basis for defining acceptability. It seems obvious that the definition should be based on some measure of the adverse effects of noise on an exposed population. But the question remains as to what specific measure should be used. The various plausible measures that have been identified and considered can be reduced to three main categories: noise impacts (specifically, activity interference and effects on health), reported annoyance, and community action (usually complaints).

Drawing almost entirely on the results of studies of human response to aircraft noise, the U.S. Environmental Protection Agency (EPA) isolates speech interference as the primary basis for defining acceptable levels of noise (1). It is reasonable to question whether this is too narrow a view and, perhaps more important, whether it is valid for noise sources other than aircraft, particularly road traffic, which, although not the most intensive, is certainly the most extensive source of environmental noise.

Basic to a rational definition of acceptability is a clear understanding of the relations among the three categories of adverse reaction previously mentioned and in turn between each of these categories and physical noise measurements. The first concern is the focus of this paper; the second is the subject of work in progress. In this paper, the relations among impacts, attitudes, and actions are examined with reference to road traffic noise by using questionnaire data collected in the Toronto-Hamilton area of southern Ontario. The paper proceeds from a discussion of the conceptual framework and the existing literature to a description of the data source. The results of the analysis are then presented, and their implications for the setting of standards for road traffic noise are discussed.

CONCEPTUAL FRAMEWORK AND EXISTING STUDIES

In a relatively early paper, Borsky called for the establishment of "an analytical model of the complex human responses to noise" (2, p. 219). In fact, he suggested a four-stage model that consists of (a) perception of noise, (b) activities affected or interrupted, (c) annoyance that results from interruption, and (d) complaints that result from this annoyance. McKennell has expressed a similar sentiment in asserting that "we require a model for the understanding and prediction of complaint" (3, p. 229).

The conceptual model that forms the basis of this analysis is sequential in nature and builds on Borsky's idea of stages of reaction to noise. However, it has been formulated so that each component is delineated more specifically for the purposes of investigation and analysis (Figure 1).

Briefly, exposure to noise is seen to affect the individual's life-style in some way. This impact can then be broadly divided into the activities that are interfered with and the effects on health that are perceived to be suffered as a result of noise. The model assumes a sequential reaction to noise whereby the direct impacts experienced by individuals are instrumental in shaping their attitude toward noise. This is not to say, however, that attitudes are a simple and direct reflection of these impacts. It is widely recognized by Borsky (2) and others such as Langdon (4) that a number of psychological factors, such as the degree to which other environmental amenities are seen as being present, intervene to complicate this link.

The model further assumes that attitudes once formed affect the subsequent actions of the individual in response to the noise, whether in the form of a complaint or some form of immediate or long-term adjustment. As McKennell (3) points out, this link too is complicated by the intervention of various factors, particularly socioeconomic variables.

Although it has been almost a decade since this conceptual framework was proposed, there has been little empirical analysis of the assumed links between the components. In general, for road traffic noise, the few empirical results reported indicate relatively weak links among the three components of the chain on which this paper focuses—namely, impacts, attitudes, and actions (4, 5, 6, 7).

In terms of the relation between impacts and attitudes, existing results fail to provide clear evidence of the relative contribution to annoyance of different forms of activity interference. In addition, no attention has apparently been paid to the link between human attitudes and reported effects of traffic noise on health. Effects on health are an equally valid and probably more significant adverse impact of noise, and it is important that they be examined. This analysis is directed toward both these ends: It examines in more detail than previously the individual and combined effects of activity interference on attitudes and examines the relation between reported effects of road traffic noise on health and attitudes.

Regarding the link between attitudes and actions, most attention has focused on the relation between annoyance and complaints (8, 9). The results consistently show that only a small percentage of those annoyed actually complain, which confirms McKennell's assertion that "the passage from annoyance to complaint is by no means straightforward nor inevitable" (3, p. 230). There is also evidence that socioeconomic variables are important intervening factors in the relation between annoyance and complaint (10).

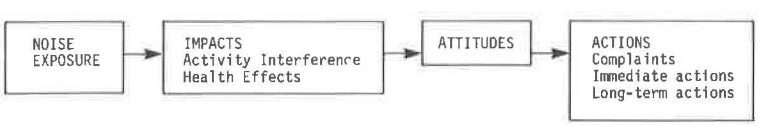
Complaining is, however, only one of many possible actions—some immediate, others more long-term—that residents can take in an effort to reduce the adverse effects of road traffic noise. In this analysis, these other types of actions are examined as well in an effort to extend and clarify the link between attitudes and actions in response to traffic noise.

DATA SOURCE

The data used in this analysis were collected in the summer of 1976 by means of a questionnaire survey of residents at selected sites adjacent to major highways in the Toronto-Hamilton area of southern Ontario. Sites were selected to cover different types of housing (i.e., single-family houses, townhouses, and apartments) and occupancy (i.e., renters and owners). A total of 949 interviews were completed at 37 separate sites. The noise measurements at each site showed the quietest site to have a daytime L_{eq} of 57 dB(A) and the noisiest a daytime L_{eq} of 80 dB(A) with a fairly even range of intervening levels.

The questions asked of respondents covered the normal range of general and specific questions included in most community noise surveys. The questionnaire,

Figure 1. Conceptual model of reaction to noise.



however, had the distinctive feature of requesting a detailed set of disturbance ratings for each noise source mentioned as disturbing. These ratings provided a measure of the degree of disturbance experienced inside and outside the home as well as the overall measure that has been obtained in previous surveys.

ANALYSIS AND RESULTS

The analysis divides into two sections. The first examines the relations between the reported impact of traffic noise (i.e., activity interference and effects on health) and attitudes. The second deals with the relations between attitudes and actions taken, both immediate and long-term. In both sections, the analysis is based on the subset of the total sample who reported being disturbed by traffic noise from a main road. This group comprised 449 of the 949 respondents.

Impacts and Attitudes

Each respondent who indicated being disturbed by main-road traffic noise was asked which if any activities were interfered with and what if any perceived effects on health any members of the household had experienced as a result of the noise. In the table below, the frequency with which activities and effects on health were mentioned shows the prominence of sleep-related impacts:

Impact	Number of Times Mentioned	Percentage of Total Sample	Percentage Disturbed
Activity interference			
Sleeping	156	16.4	34.7
Relaxing indoors	53	5.6	11.8
Relaxing outdoors	76	8.0	16.9
Conversing indoors	27	2.8	6.0
Conversing outdoors	40	4.2	8.9
Working indoors	16	1.7	3.6
Working outdoors	8	0.8	1.8
Watching television	63	6.6	14.0
Speaking on telephone	15	1.6	3.3
Eating	18	1.9	4.0
Effect on health			
Nervousness	30	3.2	6.7
Hearing loss	6	0.6	1.3
Irritability	84	8.9	18.7
Headaches	35	3.7	7.8
Sleep interrupted	228	24.0	50.8
Kept awake	110	11.6	24.5

For both activity interference and effects on health, the impact on sleep was mentioned far more frequently than any other impact. Speech interference, whether in general or in telephone conversations, was mentioned relatively infrequently; this contrasts with the results from studies of aircraft noise and suggests once more that reactions to noise cannot be dealt with independently of the noise source.

It needs to be stressed that the effects on health are those that are perceived to have occurred. Clearly, the perception may in some cases underrepresent and in other cases overrepresent the actual effects. However, given that no medical records were consulted, the degree of correspondence between perception and reality remains unknown for these data.

Four measures of attitude were used in the analysis. Each was based on a self-rating of disturbance from main-road traffic noise on a 10-point scale ranging from 0 (not at all disturbed) to 10 (unbearably disturbed). Intermediate scale points were unlabeled, and respondents could give noninteger ratings (e.g., 2.5) if they wished. This scale is assumed so that the analysis has interval properties. The four measures of attitude based on this scale correspond to the overall rating of disturbance, the rating inside the home, and ratings outside on the exposed side of the building and on the shielded side of the building. In certain residential developments, particularly apartments, the respondent's dwelling unit did not have a shielded side, in which case the shielded rating was not obtained.

The analysis of relations between noise impacts and attitudes used analysis of variance and multiple classification analysis. The impact measures form the categorical independent variables, and the attitude scores form the interval-scaled dependent variable. The effects of the different impacts are considered both individually and in selected combinations.

The relations between individual impacts and attitudes were examined by using a one-way analysis of variance (Table 1). The resulting F-ratio and associated probability indicate whether a statistically significant difference exists in the mean attitude scores between those who do and do not report experiencing each impact. The eta coefficient is a measure of the association between the reported impact and attitude. It is the appropriate measure of association where the independent variable is nominal and the dependent variable at least interval as in this case (11).

For the activity interference variables, the results show that 23 of the 40 relations examined are significant beyond the 5 percent level. When one considers the relations with overall attitude toward traffic noise, conversation, watching television, and sleep interference are the strongest predictors although the eta coefficients are not impressive. Given that eta^2 can be interpreted as the proportion of the variance in the dependent variable explained by the independent variable, interference with outdoor conversation and television watching—the strongest predictors—both account for only 2 percent of the variation in overall attitude.

The relations with the other attitude scales form a logical pattern in that indoor activities are more strongly related to indoor ratings of disturbance and outdoor activities are more strongly related to outdoor ratings. Outdoor activity interference is more strongly linked to the ratings for the exposed side of the building than to those for the shielded side.

In relation to effects on health, the relations are generally stronger; all but 2 of the 24 relations examined are significant beyond the 5 percent level. The strongest relations are with the indoor rating, which is reasonable since the effects on health considered are generally more likely to occur as a result of exposure to noise inside the home. Although the relations are stronger, the eta coefficients are still quite small. The largest eta is only 0.27 for the relation between irritability and indoor rating, which means that only 7 percent of the variation in attitude is explained.

The variables that emerged as the best predictors of attitude in the one-way analysis were included in a multivariate analysis to determine whether the impacts provided better predictions when combined than when treated individually. The results of the multiple classification analysis performed as part of the multivariate analysis of variance summarize the effectiveness of the combined predictors (Table 2). Multiple classification analysis describes the pattern of the relation between a set of nominal independent variables and an interval-scaled dependent variable (12). The relation between each independent variable and the dependent variable is examined by controlling for the effects of the other independent variables. In addition, the overall relation between the independent variables and the dependent

Table 1. Relations between individual noise impacts and attitudes.

Impact	Attitude: Overall Significance (F)	Overall eta Coefficient	Indoors Significance (F)	Indoors eta Coefficient	Outdoors, Exposed Side Significance (F)	Exposed Side eta Coefficient	Outdoors, Shielded Side Significance (F)	Shielded Side eta Coefficient
Activity interference								
Sleeping	0.01	0.14	0.001	0.21	NS	0.08	NS	0.09
Relaxing indoors	NS	0.06	0.001	0.19	NS	0.07	NS	0.03
Relaxing outdoors	NS	0.08	NS	0.04	0.001	0.17	NS	0.01
Conversing indoors	0.01	0.13	0.001	0.18	0.05	0.11	NS	0.08
Conversing outdoors	0.01	0.15	0.05	0.10	0.001	0.17		0.12
Working indoors	NS	0.08	NS	0.01	0.05	0.09	NS	0.01
Working outdoors	NS	0.04	NS	0.02	NS	0.04	NS	0.10
Watching television	0.01	0.15	0.001	0.23	0.05	0.11	NS	0.10
Speaking on telephone	NS	0.08	0.01	0.16	0.01	0.13	NS	0.10
Eating	NS	0.09	NS	0.07	NS	0.05	NS	0.01
Effect on health								
Nervousness	0.001	0.16	0.001	0.19	0.01	0.15	0.05	0.15
Hearing loss	0.01	0.15	0.001	0.17	NS	0.05	0.01	0.17
Irritability	0.001	0.22	0.001	0.27	0.001	0.16	0.05	0.15
Headaches	NS	0.09	0.001	0.16	NS	0.07	0.001	0.22
Sleep interrupted	0.001	0.21	0.001	0.25	0.001	0.21	0.05	0.15
Kept awake	0.001	0.20	0.001	0.25	0.01	0.13	0.01	0.17

Note: NS = not significant.

Table 2. Relations between combined noise impacts and attitudes.

Impact	Attitude: Overall Significance (F)	Overall R/R^2	Indoors Significance (F)	Indoors R/R^2	Outdoors, Exposed Side Significance (F)	Outdoors, Exposed Side R/R^2
Activity interference						
Sleeping	0.01		0.001			
Relaxing indoors			0.05			
Relaxing outdoors					0.05	0.211
Conversing indoors	NS	0.251	NS	0.364		
Conversing outdoors	0.05	0.063			0.05	0.045
Watching television	0.05		0.001	0.133		
Speaking on telephone			NS			
Effect on health						
Nervousness	NS		NS		0.05	
Irritability	0.001	0.331	0.001		0.05	0.289
Headaches			NS	0.412		
Sleep interrupted	0.001	0.110	0.001	0.170	0.001	0.084
Kept awake	0.05	0.001			NS	
Combined						
Conversing outdoors	0.01					
Watching television	0.05	0.332				
Irritability	0.001	0.110				
Sleep interrupted	0.001					

Note: NS = not significant.

variable is calculated. The results are valid only if the interaction effects among the independent variables are not significant. This basic condition was met for the analysis reported here.

The figures given in Table 2 indicate the significance of the effect of each impact adjusted for the effects of the other variables in the same combination and also the proportion of the variation in attitudes accounted for by the combined impacts (R^2). As expected, the adjusted effects were less significant than the unadjusted effects in all cases, which indicates that the impacts are correlated to varying degrees. A consistent finding, however, was that the difference between the unadjusted and adjusted effects was least for sleep-related impacts; this confirms the finding of previous studies (4, 5) that sleep interference is relatively independent of other traffic noise impacts.

When compared with the eta coefficients reported from the one-way analysis of variance (Table 1), the R^2 values show that the explained variation in attitudes has been increased by using a combined set of predictors, but the gain is very modest. The best prediction (R^2 = 0.17) is for the indoor rating of traffic noise based on the combined set of health impacts although only three of these—irritability, interruption of sleep, and being kept awake—have significant adjusted effects.

In summary, these results confirm previous findings in two respects. First, they show that attitudes toward traffic noise are significantly related to the adverse impacts of the noise that an individual has experienced, and to this extent the link between impacts and attitudes in the conceptual model is supported. Second, however, the results show that this link is by no means a simple cause-and-effect relation. The proportion of the variation unaccounted for by the impacts indicates that intervening factors play an important role in shaping attitudes. These results go beyond those previously reported in showing that reported impacts on health are more strongly related to attitude than are the activity-interference variables. Furthermore, they indicate that sleep-related impacts are generally the ones most significantly related to reported disturbance from road traffic noise.

Attitudes and Actions

Information was obtained from each respondent disturbed by main-road traffic noise to determine what actions, if any, had been taken to reduce the impact of noise. Besides information on complaint action, respondents indicated what other immediate or longer term actions they had taken. In the table below, the number of times the actions included in the analysis were mentioned shows how few people have complained:

Action	Number of Times Mentioned	Percentage of Total Sample	Percentage Disturbed
Complaint	24	2.5	5.4
Immediate			
Close windows	244	25.7	54.3
Stay inside	61	6.4	13.6
Turn television on or up	112	11.8	24.9
Any of above	284	29.9	63.3
Long-term			
Erect barrier	36	3.8	8.0
Consider moving	261	27.5	58.1

This again underlines how unrepresentative complaint action is as an index of disturbance or annoyance. This is perhaps more the case with traffic noise from a main road than with noise from other sources because it is rarely possible to isolate the cause of disturbance other than in the most general terms and this provides little basis for formal complaint.

Immediate, short-term actions designed to reduce the impact of noise are much more common and, of these, closing windows was the most frequently reported. Longer term actions were again generally less frequent. The erection of barriers (fences, walls, or trees) is singled out here for inclusion in the analysis. Information on other actions was obtained in the questionnaire, but they were not mentioned frequently enough to warrant analysis. Respondents were also asked whether they had ever considered moving to avoid unwanted noise. Over 58 percent of those disturbed by main-road traffic noise said yes. Clearly, many who mention having considered moving may have little or no intention of doing so. Nonetheless, the responses are included in the analysis to determine to what extent they are a function of attitudes.

Stepwise discriminant analysis was used to analyze the relations between attitudes and actions. The purpose of this technique is to define the linear combination or combinations of independent variables that maximally discriminate between the groups defined by the categories of the dependent variable (13). In this analysis, the independent variables were the four attitude scales previously described, and the groups comprised those who had and had not taken each of the seven actions given in the preceding table. Seven separate analyses were therefore performed to examine the relations between attitudes and each of the actions.

From the results given in Table 3, it is obvious that each of the seven actions is dominated by a single attitude variable. In five cases, only the first variable entered into the equation makes a significant contribution to the action that reflects the degree of correlation among the scales. In three instances, the dominant variable is the overall rating; in two others, it is the outdoor exposed rating; and in the remaining two, it is the outdoor shielded rating. The indoor rating makes no significant contribution to any of the actions. It must be borne in mind that the significance referred to here is based on the combined attitude variables. When the attitude variables were considered individually, each of the four was found to be significantly related to each of the action variables.

The canonical correlation for each function provides a "measure of association between the discriminant function and the set of (g - 1) dummy variables which define the g group memberships" (14, p. 442). Based on these coefficients, the relation between attitudes and actions is strongest for "consider moving" followed by "any of above" and "turn television on or up". Although each of the functions significantly discriminates between the groups defined in the action variables, the relation between attitudes and actions reflected in the canonical correlations is at best moderate and in most cases weak.

Further evidence of this weak relation is seen in the percentage of cases correctly classified into the two groups on each action variable by using the discriminant scores for each case. The stronger the relation is between the predictors and the group variables, the greater the discriminating power of the function and the more accurate the classification of group membership are. With two groups and equal prior probabilities of membership in each, 50 percent accuracy in classification could be expected in the long run on the basis of chance alone. The results show that knowledge of respondents' attitudes toward road traffic noise provides better predictions of action than could be expected by chance, but nevertheless an accuracy that ranges from

Table 3. Results of discriminant analysis: attitudes and actions.

	Attitude									
					Outdoors					
	Overall		Indoors		Exposed Side		Shielded Side			
Action	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance	Canonical Correlation	Group Members Correctly Classified (%)
Complaint	0.23	NS	-0.41	NS	0.58	NS	0.64	0.001	0.24	63
Short-term										
Close windows	-0.56	0.001	-[a]	-[a]	-0.35	NS	-0.25	NS	0.22	60
Stay inside	-[a]	-[a]	-0.15	NS	-0.57	0.001	-0.47	NS	0.24	61
Turn television on or up	-0.37	0.05	-0.06	NS	-0.18	NS	-0.60	0.001	0.32	67
Any of above	-0.49	0.001	-0.04	NS	-0.42	NS	-0.25	NS	0.32	65
Long-term										
Erect barrier	-0.75	NS	0.41	NS	-0.55	0.01	-0.12	NS	0.22	63
Consider moving	-0.62	0.001	-0.22	NS	-0.37	0.05	-[a]	-[a]	0.41	67

Notes: Coefficients are standardized discriminant function coefficients. Significance of the contribution of each variable to the function is based on change in Rao's V.
NS = not significant.

[a] The variable failed to meet the entry criterion based on partial F-ratio.

a low of 60 percent to a high of 67 percent is not impressive.

Considering the following complete classification table for the complaint variable leads to a better understanding of the implications of this relatively poor level of prediction:

	Predicted Group				
	No Complaint		Complaint		
Actual Group	Number	Percent	Number	Percent	Total
No complaint	139	62.6	83	37.4	222
Complaint	7	30.4	16	69.6	23
Total	146		99		245

The figures show that 83 (37.4 percent) of those who had not complained were indistinguishable in terms of their attitudes from those who had complained. Further, 7 (30.4 percent) of the complainants were indistinguishable from the noncomplainants. This overlap confirms the unreliability of complaint action as an index of annoyance. A substantial percentage of those who have not complained are clearly as much disturbed by road traffic noise as the complainants. In light of this finding, the adequacy of regulating against traffic noise in response to complaints must be seriously questioned.

In summary, the relations between attitudes and actions taken to reduce noise impacts are similar to those previously examined between impacts and attitudes in that they are significant but not strong. Here, again, a simple cause-and-effect relation is confounded by the effects of various intervening variables. The question that now has to be addressed is that of the implications of the relation that have been described in this section, specifically in terms of their importance for setting noise standards.

CONCLUSIONS AND IMPLICATIONS

This paper began by asserting the need to examine the interrelations among noise impacts, attitudes, and actions to provide a better basis for setting standards on acceptable levels of road traffic noise. The immediate problem was seen to be that of deciding on a criterion of acceptability. In this section, the implications of the results previously described are discussed with reference to this problem.

Considering first the relations between the reported impacts of noise (i.e., activity interference and effects on health) and human attitudes, it is clear that there is far from a one-to-one correspondence between the two. This is evident from the fact that many more people reported being disturbed by traffic noise than indicated having experienced specific activity interference or effects on health and also from the weak correlation between the impacts—both individually and in combination—and attitudes. This clearly implies that setting some standards with the aim of eliminating specific noise impacts will not totally eliminate annoyance. This has been recognized in previous studies (1) where the conclusion has been that there appears to be no practical way of setting standards so as to ensure the elimination of annoyance. Although the results of this analysis would in some ways seem to lead to the same conclusion, a word of caution is necessary. The extent of the disparity between the reported impacts of road traffic noise and reported disturbance that is evident in these data makes questionable the adequacy of setting standards on the basis of impacts alone. To do so may well leave an unacceptably large percentage of the population annoyed. The strategy adopted by EPA (1) of recommending a standard 5 dB(A) below that required to eliminate impact (in that case, speech interference) as a margin of safety may not be sufficient. It seems necessary to go beyond this kind of ad hoc approach to the problem and carefully compare the relations between noise levels and annoyance with those betwen noise levels and reported impacts. This is the approach that we have adopted in our own analysis in progress.

The results of this analysis also provide a basis for assessing the appropriateness of using speech interference as the criterion for defining acceptable levels of road traffic noise. The choice by EPA of speech interference as the critical factor was defended on the grounds that it "has been identified as the primary interference of noise with human activities, and as one of the primary reasons for adverse community reactions to noise and long-term annoyance" (1, p. D-34). However, the empirical findings to substantiate this statement are almost exclusively confined to aircraft noise, and the question arises as to whether the results of studies of road traffic noise are equally supportive.

The results of this study strongly suggest that they are not. Speech interference was far from being the primary type of activity interference reported. Nearly four times as many people mentioned sleep interference as mentioned interference with outdoor conversation. Interference with conversation was also exceeded by reports of interference with relaxation. The strength of the relation between speech interference and attitudes implied by the EPA statement is not strongly supported either. Of the activity interference measures, those that involved speech interference were the most strongly related to the attitude scales (Table 1), but the correlations were relatively weak. Furthermore, several of the effects on health emerged as better predictors of attitude than did speech interference.

The general conclusion seems to be that the universal adoption of speech interference as the criterion for setting acceptable levels of noise is dubious. There are good practical reasons for using speech interference (specifically, the ability to accurately gauge the degree of interference caused by different noise levels), but these alone are insufficient to defend the adoption of speech interference as the critical criterion for standards on road traffic noise if the empirical justification is lacking.

The fact that reported effects on health generally emerged as better predictors of attitude than did the variables of activity interference suggests that the impacts of noise on health deserve more consideration in the setting of noise standards than they appear to have received. Admittedly, there are practical problems involved in this since it would be necessary to go beyond the reported effects on health used in this analysis and consult medical records to assess the effect of noise on health with any degree of reliability. Even if records were accessible, there would still be problems in isolating the effect of noise among the many potential variables that affect health. Nevertheless, the effects of noise on health still warrant consideration as possible criteria for setting standards.

The basic implication of the relations between attitudes and actions is to confirm the need for specific standards for road traffic noise. Given the ambiguous wording of many existing environmental regulations, the status quo approach to regulating noise levels has been to respond to complaints. The results of this analysis confirm those of previous studies: Regulating on the basis of complaints is totally inadequate. This is evident from the fact that only a very small percentage of those disturbed had ever complained and also from the weak relation between attitudes and complaints shown by the discriminant analysis. The unreliability of complaints as an index of disturbance is further underlined by comparing the small number of complainants with the much larger number of people who had taken immediate actions to reduce intrusion from noise or who had considered moving to a quieter neighborhood.

This analysis in itself is clearly not a sufficient basis for drawing final conclusions on criteria for setting standards on road traffic noise. Nonetheless, this examination of the relations among impacts, attitudes, and actions provides important empirical findings that can serve as a partial basis for regulatory decisions.

The results of this analysis must be considered in relation to those derived from an analysis of the relations between the various impact and response measures considered here and measurements of noise level. That type of analysis is the focus of work in progress. Taken together, the results of the two analyses will significantly strengthen the existing empirical basis for decisions on standards for road traffic noise.

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Effectiveness of Shielding in Reducing Adverse Impacts of Highway Traffic Noise

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Construction of noise barriers or other forms of shielding between residential areas and noisy roadways is one of several approaches to reducing community noise levels. Some studies have suggested that the psychological effect of such shielding is greater than its acoustical effect. This suggestion was tested by using home interview data from five pairs of residential sites. The two sites that made up each pair experienced the same noise level at dwellings but had different types of shielding or barriers. It appears that there is no psychological effect for road traffic noise specifically but that there is an effect for attitudes toward overall community noise. This psychological effect appears to be negative for solid noise barriers, low for single rows of trees, and highest for a row or rows of intervening housing.

Many jurisdictions are in the process of implementing a variety of procedures for reducing the level of traffic noise that reaches residential areas. For example, in the United States, the Federal Highway Administration will provide funding for traffic management procedures to reduce noise, for the construction of noise barriers, or for the purchase of land for such construction or to serve as a buffer zone (1). In Ontario, the Ministry of Transportation and Communications has earmarked funds for construction of noise barriers along major highways through residential areas. In Britain, the government has undertaken to insulate houses for purposes of sound reduction wherever the existing sound level exceeds certain standards. Other agencies (the U.S. Environmental Protection Agency and the Canada Ministry of Transport, for example) are acting to reduce the noise produced by motor vehicles, especially trucks.

Given this variety of expensive actions to reduce noise, it seems pertinent to ask whether such actions are as effective in reducing the impact of noise on people as they are in reducing physical sound levels. All of the efforts mentioned above are predicated on the assumption that physical measures of sound are reliable indicators of the effects of noise on people. That is, these efforts assume that the kind of aggregate relations between traffic noise and response to it that many people have reported (2, 3, 4) can be applied directly to any situation in which sound levels caused by traffic are somehow reduced. This paper provides an empirical test of that assumption for one of the proposed actions—that of installing some kind of barrier or shielding between the highway and the residential area.

There are three reasons for focusing on this situation rather than on building insulation or on reduction of noise at the source:

1. It is obvious that shielding is a more comprehensive approach to noise reduction than building insulation. Insulation does not affect outdoor levels of noise at all, and the use of outdoor space in residential areas is an important part of home life in North America.
2. Transportation agencies are increasingly turning to the construction of barriers and buffers as one of the few methods under their control for reducing the effects of highway noise (5).
3. It is not obvious what the "impact effectiveness" of barriers (i.e., the effectiveness of the barrier in reducing adverse impacts) is as opposed to their acoustical effectiveness. It may well be that the two types of effectiveness are equivalent and acoustical measurement is thus a reasonable surrogate for impact measurement, as most agencies currently assume. Two other possibilities exist, however, both of which are as plausible a priori as equivalent effectiveness. On the one hand, impact effectiveness may be considerably less than acoustical effectiveness. Despite shielding, residents are still aware of the presence of a highway, and the reduced noise levels may only remind them of their proximity to the facility and lead to more annoyance, complaints, and activity interference than one would otherwise expect from the sound-level readings. On the other hand, impact effectiveness may be greater than acoustical effectiveness. Andrew and Sharratt (8), among others, suggest that a number of other highway effects, such as headlight glare, dust, or winter salt spray, are mixed in with any responses to highway noise so that eliminating these will cause adverse reaction to traffic noise to be less than one would expect from the sound levels.

It seems clear that the cost-effectiveness of shielding for noise along highways must ultimately be expressed in terms of what it does for people rather than simply what it does for sound levels. Consequently, it is important to know whether acoustical effectiveness and impact effectiveness are identical or whether perhaps greater or lesser sound level reductions are required for a certain target level of reduction in impacts. This paper investigates responses to road traffic noise in a number of residential areas that have some form of shielding between them and the highway. The impact effectiveness of the shielding is analyzed by comparing responses at each site with the responses to traffic noise at a second site that experiences the same sound levels at dwellings but is either unshielded from the road or is shielded by different material.

SUGGESTIONS FROM PREVIOUS STUDIES

Several earlier studies have suggested that the impact effectiveness of shielding is greater than the acoustical effectiveness. As early as 1972, one study in Toronto noted that, though a particular experimental barrier had not significantly reduced sound levels (yielding reductions of only 1 or 2 dB(A) in L_{10} and L_{50} at residences), "people living behind the barriers considered them beneficial" (9, p. 13). Reasons for this reaction were not investigated, but the authors suggested that the effects of shielding in relation to dirt, debris, and the sight of traffic might be important.

A more recent study in Toronto focused on changes in these latter highway effects, in addition to noise, after the construction of a privacy fence (8). The fence, a solid steel wall, accomplished a reduction in sound levels of from 5 to 7 dB(A) and led to some reduction in annoyance from traffic noise 6 months after construction. However, 12 months after construction, annoyance had risen again (although not to prefence levels). Furthermore, in the second row of housing away from the highway, some residents reported greater annoyance than before the fence was constructed, commenting that the sound "bounced over" the fence whereas previously they had felt that it was "absorbed by the first row of houses" (8, p. 33). That study also reported but was unable to explain satisfactorily that the reduction in annoyance was least at those houses in the first row where the reduction in sound level was greatest whereas other houses in the first row experienced less reduction in noise levels. It appears from that study that the impact of shielding is not obvious and that more needs to be known about it.

Other studies have been more definite in their conclusion that impact effectiveness is greater than the acoustical effectiveness of barriers (7, p. 16) and explain it by the conjunction of the visual screening with the noise reduction. Other studies have also noted the possible beneficial effects of visual screening (10). Because visual screening is important, the appearance of the barrier itself also becomes important (7). (The rather stark appearance of the Toronto barrier studied by Andrew and Sharratt may be part of the reason for the decrease in its impact effectiveness between the 6- and 12-month data collections.)

The appearance of the barrier is also emphasized in a study of the subjective and physical effects of noise barriers at Heston, England, by Scholes and others (11). Measurements were taken with a board fence, with no barrier, and with an experimental barrier. The barrier was found to reduce noise levels by 3 to 9 dB(A) (based on an L_{10} measurement) below the noise level experienced when there was no fence and to improve the reduction beyond that caused by the fence by approximately 4 dB(A). The population interviewed recognized that the noise in the neighborhood had decreased, but a considerable number disapproved of the barrier because of its unsightly appearance.

There is, however, another study that raises questions about this visual effect that have not been considered in these previous studies. Aylor and Marks (12) report that visual shielding is not tied so simply to the impact effectiveness of a barrier. Partial visual shielding results in a reduction in the perceived loudness of noise; full visual shielding does not (12, p. 400). The psychological effect can be the equivalent of as much as 7 dB(A) in sound pressure level. This may help to explain some of the anomalies of previous studies, such as that reported by Andrew and Sharratt in which some people in the second row of housing reported increased annoyance after the fence was constructed (8). Aylor and Marks express caution in applying these findings, however, especially with respect to the stability over time of the psychological effect, which could not be covered in their necessarily artificial experimental study design.

DATA FOR ANALYSIS

As part of the study design for data collection conducted during the summer of 1976, we deliberately selected a number of sites that had different types of shielding between the houses and the roadway so as to examine in a real-world setting the effects on response to noise suggested by these earlier studies. Each site consisted of a single row of housing parallel to the roadway in question and containing 40 or more units. No other major sources of noise affected any site; that is, they were not near industrial areas, rail lines, or airports.

At each site, 25 to 30 households were interviewed by using an extensive questionnaire that was slightly modified from one used in a similar collection of data in 1975. The questionnaire was introduced as a general neighborhood attitude survey; then the focus on noise was explicitly stated to facilitate collecting detailed information on attitudes to noise, activities interfered with by noise, perceived effects of noise on health, and actions taken because of noise—all with reference to the specific sources of noise mentioned by the respondent. The standard personal data were also collected.

After completion of all interviews at each site, a 24-h record of noise levels was taken. Three different kinds of equipment were used for this purpose: (a) a timer-activated Uher 4200 Report Stereo tape recorder that sampled at the rate of 55 s every 12.5 min, (b) a DA603A digital monitoring device that sampled once per second, and (c) a BBN model 614 noise monitor system that sampled every half second. All field devices were calibrated at the start and end of each monitoring session by using a GR1567 sound-level calibrator. The Uher recordings were subsequently analyzed by using a B&K microphone amplifier (to obtain the A-weighting), a level recorder, and a statistical distribution analyzer with 5-dB(A) intervals. The other two devices provide A-weighted readings directly. In keeping with the practice of one of the project sponsors, the Ontario Ministry of the Environment, sound levels have been separately analyzed for three time periods: daytime (7:00 a.m. to 7:00 p.m.), evening (7:00 to 11:00 p.m.), and night (11:00 p.m. to 7:00 a.m.). For each period, L_{99}, L_{90}, L_{50}, L_{10}, L_1, and L_{eq} have been calculated. These time periods do not allow exact calculation of the day-night equivalent sound level L_{dn}, so we have calculated a day-evening-night equivalent level L_{den} by applying a 5-dB(A) penalty to the evening L_{eq} and a 10-dB(A) penalty to the nighttime L_{eq}. This provides a single number for direct comparison of noise levels at different sites.

On the basis of this information, all sites in both the 1975 (13) and 1976 (14) data-collection efforts were considered to find pairs of sites with sound-level readings at residences that were as similar as possible and with different kinds or degrees of shielding between the housing and the road. Five pairs of sites were identified (Table 1). The acoustical effectiveness of the barrier or shield was not investigated.

The sound levels at the housing units are the same in each pair, but the noise generated by the road is not. For example, the first pair compares the responses of people in the second row of housing along the Queen Elizabeth Way, which has a traffic volume of almost 90 000 vehicles/d, with the responses of people who live adjacent to Dixie Road, which carries fewer than 30 000 vehicles/d. Clearly, the noise at the road edge is much higher in the first instance than in the second. The point is that the sound levels at the residences are the same for each pair of sites, as shown by the monitor readings given in Table 1. Although the L_{den} was used as the principal identifier of similar sites, L_{eq}, L_{10}, and L_{50} for each of the three periods are also reported to allow more detailed comparison.

For each pair of sites, a large number of variables from the household interviews were investigated to see if there were any significant differences between the two sites in the responses. Two variables deal with the overall attitude of people toward the noise in their neighborhood: (a) whether or not the respondents volunteered that noise was something they disliked about their neighborhood and (b) their rating, on a nine-point bipolar scale (from extremely agreeable to extremely disturbing), of the overall noise. The remaining variables deal with responses to specific noise sources, which in this analysis have been limited to the main road in general and trucks in particular. For each of these sources, there are sets of variables that deal with attitudes, activity interruption, actions taken, and perceived effects on health.

Attitudes were measured three ways: (a) by whether or not the person volunteered that the specific source was a noise he or she noticed, (b) by a rating on an ordinal nine-point bipolar scale for each person who mentioned the noise source, and (c) by a rating on an

Table 1. Descriptions of site pairs for analysis.

		Sound Level (dBA)									
			Daytime			Evening			Nighttime		
Site Pair	Type of Shielding	L_{den}	L_{eq}	L_{10}	L_{50}	L_{eq}	L_{10}	L_{50}	L_{eq}	L_{10}	L_{50}
1											
Queen Elizabeth Way, row 2	One row of housing	65	62	60	55	60	61	56	57	58	54
Dixie Road	Single row of trees	64	61	63	58	60	61	57	55	58	53
2											
Stevenharris	Several rows of housing	68	67	66	63	63	63	61	60	61	57
Sterling Street	None	68	68	70	58	65	68	55	60	61	53
3											
Horizon Village	Concrete wall (3.7 m high)	70	69	64	61	63	64	59	62	63	60
Garth Street	None	69	67	70	59	65	69	59	61	62	50
4											
Islington North	Single row of trees	76	74	77	72	72	76	70	67	72	64
Islington South	None	76	74	77	72	72	76	69	67	72	57
5											
Islington North	Single row of trees	76	74	77	72	72	76	70	67	72	64
Upper James	None	77	73	76	69	71	74	66	70	72	58

Note: 1 m = 3.3 ft.

interval-level disturbance scale for each person disturbed by the noise source. Activity interruption is based on whether or not the respondent volunteered the information that any of the following activities were interrupted by noise from each source:

1. Sleeping,
2. Relaxing indoors or outdoors,
3. Conversing indoors or outdoors,
4. Working indoors or outdoors,
5. Watching television,
6. Conversing on the telephone, and
7. Eating.

Information on actions taken derives from the following list that was read to the respondent:

1. Close windows;
2. Use air conditioning;
3. Stay indoors;
4. Turn television, radio, or records on or up;
5. Wear earplugs;
6. Wait for noise to stop;
7. Take individual complaint action; and
8. Take organized complaint action.

Respondents were also asked if the specific noise source had any effect on their family's health; the following items were specifically mentioned:

1. Nervousness,
2. Hearing loss,
3. Irritability,
4. Headaches,
5. Sleep interrupted, and
6. Kept awake.

Thus, in addition to the two variables on overall attitudes to noise, there are a total of 27 source-specific responses available for analysis.

RESULTS OF THE ANALYSIS

Despite the large number of variables available for analysis for each of the five pairs of sites, the method of analysis is quite straightforward. All we are examining is whether the response to the same noise level is different when different types of shielding or barriers are present. Given the nature of most of the variables (i.e., nominal or ordinal, with one exception), this comparison can be accomplished by means of several simple statistical tests: a chi-square test for the nominal variables; the Mann-Whitney U-test for the ordinal variables; and a t-test for the interval rating scale. For this particular problem, the results of such tests will be informative no matter what the outcome. If there is no significant difference between responses at the two sites in each pair, it suggests that the present working assumption—that acoustical measurements are good surrogates for noise impacts—is correct. On the other hand, if there is a significant difference in responses at the two sites, it would strengthen support for the suggestion that shielding has some kind of psychological effect over and above its acoustical properties (or it could suggest a negative psychological effect, depending on the direction of the relation). It may well be the case that such a psychological effect exists for some impacts and not for others. For this reason, the results are discussed by the main categories of variables listed in the previous section.

In all five pairs of sites, there is a significant difference in attitude toward overall community noise (Table 2). In two of the five pairs, the difference is in the number who volunteer noise as a problem; in the other three pairs, the difference occurs on the rating scale. Pair 1 indicates that a single row of housing is more effective in improving such attitudes than a single row of trees that grow close together and provide a visual screen. Pair 2 indicates that several rows of housing are more effective than no shielding at all, and pair 3 suggests that no shielding at all is more effective than a solid concrete wall. The remaining two pairs suggest that a screen of trees is more effective than no shielding at all (but note that the same shielded site is used for both comparisons). Consequently, if one is willing to postulate transitivity for such comparisons of effectiveness, the apparent effectiveness of these several types of shielding in improving attitudes toward overall noise in a neighborhood is as shown in Figure 1.

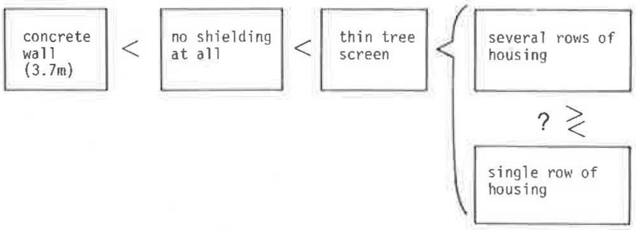
There is considerably less effect when one looks at variables that refer directly to main-road traffic noise. There is no significant difference in attitudes toward traffic noise in four of the five pairs for any of the three variables analyzed. It is important to note, therefore,

Table 2. Significant levels of variables for tests of association.

Variable	Site Pair 1	2	3	4	5
Comparison of shielding					
a	One row of housing	Several rows of housing	3.7-m concrete wall	Trees	Trees
b	Screen of trees	Nothing	Nothing	Nothing	Nothing
Attitudes toward overall community noise					
Dislike noise (volunteered)	ND	ND	ND	0.05 (a > b)	0.01 (a > b)
Overall noise rating	0.05 (a > b)	0.01 (a > b)	0.001 (a > b)	ND	ND
Responses to noise from main road					
Attitudes	ND	Mention of road, 0.01 (a > b)	ND	ND	ND
Activity interference	ND	ND	ND	Relaxing outdoors, 0.05 (b > a)	Relaxing indoors, 0.05 (a > b); Working indoors, 0.05 (a > b)
Actions taken	Close window, 0.05 (a > b)	ND	ND	ND	ND
Effects on health	Sleep interrupted, 0.05 (a > b)	ND	ND	ND	ND

Notes: 1 m = 3.3 ft.
ND = no difference.
a > b or b < a means that type of shielding a is more effective than type b or vice versa for the particular impact. All variables not reported in the table showed no significant differences between sites.

Figure 1. Comparative effectiveness of types of shielding for improving attitudes toward overall community noise.



that Figure 1 applies only to attitudes toward overall community noise and not to attitudes toward noise specifically from road traffic. Similar findings resulted from the examination of variables that refer to truck noise. No significant difference in attitudes toward truck noise was found in any of the five pairs.

For activities interfered with by main-road traffic noise, there are significant differences at only two of the five pairs of sites. These relate to relaxing (outdoors at pair 4 and indoors at pair 5) and working while indoors (pair 5). The remaining seven activities covered in the questionnaire show no significant differences in the amount of interference by traffic noise at any of the five pairs. In other analyses of the full data set, including that of Taylor, Hall, and Gertler in another paper in this Record, relaxing and working have not shown up as particularly important activities. This, together with the fact that each of these specific activity interferences is statistically significant at only one of the five pairs of sites, leads us to discount the substantive significance of these particular results. In essence, we would argue that a result that appears at only one of the five pairs needs a much tighter confidence limit. If a result has a probability of 0.05 of occurring by chance in the data for a site, it follows that in investigating results for five sites there is a probability of almost 0.23 of seeing such a result at at least one site. Consequently, we would conclude that, for activity interference variables as well as attitude variables, there are no meaningful differences between types of shielding when people are talking specifically about road traffic noise.

Similar reasoning applies to the results for both actions taken and health effects. In each case, only a single variable of the eight action or six health variables shows up as significant and these only at a single site. It is possible, as it was for activity interference, that it is only this particular comparison of types of shielding that has an effect. In that case, one must conclude that a single row of housing is more effective than a screen of trees in reducing the extent to which people must close their windows to reduce noise or the extent to which sleep is interrupted. But we are influenced more by the general tendency of all of the variables at all of the sites, and we would conclude that there is probably no meaningful difference in types of shielding with respect to actions taken or to the perceived effects of road traffic noise on health. There are no significant differences for any of the above variables in response to truck noise.

CONCLUSIONS AND IMPLICATIONS

The results of this analysis are both reassuring and cautionary. They support a number of previous findings but also go beyond them.

The reassuring part of the results is that all forms of shielding investigated appear to be equally effective with respect to a large range of responses to road traffic noise. Given that the sound level at the dwelling is the same, attitudes, activity interference, actions taken, and perceived effects on health are not significantly different at two locations with different kinds of shielding. The working assumption that the measurement of sound level is a reasonable surrogate for the measurement of the impacts of road traffic noise is supported. It follows that any barrier that reduces sound levels will also reduce impacts equally.

The cautionary part of these findings is that they apply only to source-specific reactions. There does appear to be a significant difference in the effectiveness of different kinds of shielding with respect to the attitudes of people toward overall noise in their neighborhoods. As a result, it would appear that one could prove or disprove the psychological effectiveness of a particular barrier depending on what one asks. If questions are addressed specifically to traffic noise, the barrier will be shown to be effective. If questions relate to general or overall noise levels, the barrier may not prove effective.

For overall neighborhood noise, the findings support and extend the experimental results of Aylor and Marks (12) as well as the findings of previous barrier studies. Aylor and Marks noted a beneficial psychological effect of partial visual screening compared with full screening but were cautious about the temporal stability of this effect. Our results support the notion of such an effect and also imply that it is relatively stable over time since the data are derived from persons who live at each site rather than being exposed only briefly to each source as in the experiment of Aylor and Marks. The effect of visual screening appears to be more complicated than in their results however. In Figure 1, situations that imply full visual screening appear at both ends of the range of effectiveness—a concrete wall at the low end and several rows of housing at the high end (again, assuming that the relations identified in Table 2 are transitive).

Unfortunately, we are forced to resort to conjecture to explain this somewhat unexpected result. It is generally accepted that noise causes adverse attitudinal reactions not simply as a result of its level but also because of meanings associated with it. For example, a rushing stream may generate as much sound as a roadway but hardly ever leads to as much annoyance. A concrete wall removes the sight of a road, but not all the characteristics associated with the traffic. People who live in such a situation are constantly reminded by the noise that they live next to a busy highway. Several rows of housing constitute an effective visual screen, but they also serve to put distance and other people between a resident and the highway. Consequently, the negative associations of the noise are more remote and not necessarily a part of the neighborhood in question. It is important to note, of course, that two such sites were not directly compared in this analysis (clearly, the noise is much less at the latter type of site). Rather, each was compared with a site that had similar noise levels.

The question that remains unanswered by this analysis and that seemed intuitively obvious before the study by Aylor and Marks (12) is whether adding trees or other landscaping to an effective sound barrier improves attitudes in any way. Our results indicate that a screen of trees has more impact effectiveness than a concrete wall. This would seem to be a simple matter of aesthetics: The former is more pleasant to look at than the latter. The suggestion of Aylor and Marks–that the difference might be attributable instead to being able to see the source—needs further investigation. Certainly, in their experiment the more aesthetic barrier was a cedar hedge that completely hid the source rather than a snow fence. A study of the effect of the appearance of barriers on attitudes would seem useful given the amount of money that has been and will be spent on improving such appearances (7).

The important conclusion of this analysis depends on whether one construes the problem of traffic noise narrowly or broadly. If one sees the problem narrowly, then this study suggests that the adverse effects specifically attributed to road traffic noise are equally affected no matter what shielding is used. If one sees the problem as one related more generally to the quality of life in urban areas, the type of shielding used does appear to have some effect. This in turn argues for the importance of an explicit study of the effect of the visual appearance of barriers. An acoustically effective barrier will clearly reduce the adverse effects of traffic noise. Will an aesthetically pleasing barrier improve general attitudes even more?

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Effects of Highway Noise on Residential Property Values

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Previous studies of highway noise have shown an effect on the price of housing that seems to vary considerably with location. In this analysis, six sites that consist of similar housing in parallel rows adjacent to major roads were identified, and data on real estate transactions and noise levels were collected. Analysis of variance indicated that there were significant differences in price between rows of houses only at the two noisiest sites. Consequently, multiple regression analysis was performed for two subsets of the sites based on noise level. The results show that at very noisy locations [daytime L_{eq} of 73 dB(A) or higher] noise is strongly related to differences in housing prices and is valued at approximately $650/dB. At less noisy sites [daytime L_{eq} less than 70 dB(A)], noise is not significantly related to differences in housing prices. These results suggest that some noise impacts are not a linear function of sound level and that noise reduction at very noisy locations is more important than at less noisy ones.

Noise from road traffic has been recognized as an environmental problem in many countries, and many studies have documented the relation between traffic noise and annoyance (1, 2, 3). As these countries have begun efforts to reduce traffic noise, or at least its adverse effects, it has become obvious that this reduction cannot be accomplished cheaply. The construction of effective noise barriers is perhaps the least expensive approach, and even this is costly. Other approaches to noise reduction, such as sound insulation of buildings and reduction of noise at the source through vehicle modification, are considerably more expensive. Even land-use controls on properties near highways are indirectly if not directly expensive.

Noise reduction efforts must compete with other environmental improvement projects and in fact with the whole range of government and private expenditures. How are noise-related projects to be justified in the competition for tight funds? Studies that detail the relation between noise and annoyance or between noise and activity interference are informative and are useful for specifying the nature of the problem of noise. However, such consequences of noise cannot compete with such obvious threats to public health as water and air pollution. Annoyance—even a high level of annoyance—does not seem a particularly compelling reason to spend large amounts of money on noise reduction.

Complaints, the tangible manifestation of annoyance, may of course be compelling in specific instances, but they are not appropriate as the basis for a national or regional program. Several studies have shown that the occurrence of complaints is affected by variables of socioeconomic status whereas the level of annoyance and other adverse effects of noise are not (4). As a result, a program based on complaints would be inequitable. Even more important, a program based on complaints must necessarily be reactive rather than preventive. It could identify problem areas only after they occurred rather than before a highway or development was constructed. Consequently, the ultimate cost of such a program would undoubtedly be much higher than would the cost of a preventive program.

There appear to be two consequences of excessive traffic noise that would be effective arguments for the expenditure of large amounts of funds on noise reduction efforts. The first is some measure of the direct economic consequences of highway noise. The second is a clear statement of the effects of road traffic noise on health—either as it affects morbidity rates or as it causes increased health-related expenditures.

In general, these effects might in fact be the best arguments for government action on environmental matters. In the first case, if there are measurable monetary effects of noise, then it would appear that the population generally recognizes and can put a price on the benefits of (comparative) quiet. If so, present transportation construction efforts do not involve adequate compensation for the disbenefits they cause people, and it seems obvious that this should be corrected. (It might also mean that construction of barriers on existing roads results in a "windfall" benefit to property owners who have purchased since the highway began generating significant levels of noise, which might be a reason for shared-cost arrangements.) In the second case, if traffic noise has unrecognized effects on the health of people who are exposed to it for long periods of time, government bodies are the only ones with the ability to act, and it would seem most important to keep the adverse effects on health of their own projects to a minimum.

The question of effect on health is beyond the scope of this paper but is clearly a problem that warrants detailed attention in the near future. People who live near highways feel that traffic noise affects their health, most obviously in terms of irritability and sleeplessness (see the paper by Taylor, Hall, and Gertler elsewhere in this Record). Are they right? Do these effects in turn lead to other problems such as high blood pressure or ulcers? Some people have suggested that they do (5), but there are as yet no clear answers. A definitive study is needed.

This paper investigates the direct economic consequences of road traffic noise on the prices of residential property. Residential land use is probably the most sensitive to noise of any activity likely to be located adjacent to roadways; it also provides more sales data than any other land use would. The effects of transportation noise on residential property values have been studied before for both highway and aircraft noise. Those earlier studies offered some suggestions about analytical methods and also raised a number of questions that require further study.

The obvious way to approach a problem of this type is to use multiple regression analysis; this should include some measure of noise at each housing unit and numerous housing characteristics as the independent variables to explain housing prices. This approach is taken in a study by Gamble, Sauerlender, and Langley (6) that found a significant effect of noise levels on housing prices. Their data came from four residential areas in the eastern United States and consisted of household interviews, property sales data from 1969 to 1971, and data on noise level and air pollution level. Their findings indicate that noise level was significant in explaining a variation in property values in all four communities and that there was an average loss of \$2050/property abutting the highway. This result is supported by Langley's further analysis of one of the four areas (7). Although these multiple regression analyses produced clear results on the relation between prices and noise, there are also some surprising results. For example, the number of bedrooms in the home was a significant variable at only two of the four sites, and the presence of a finished basement was significant at only one of the four. Most likely there was not sufficient variation at each of the other sites for these variables to enter the analysis. Another possible problem with multiple regression, however, is that it will not be effective in identifying all relevant variables because of multicollinearities in the data.

The more striking result was the large variation in the effect of noise among the four sites. Dollars-per-decibel values ranged roughly from \$60 to \$600; this variation was not adequately explained. If the variation really is of this order, then economic effects cannot be used with much confidence in decisions on highway location or barrier construction.

Studies that attempt to relate housing prices to aircraft noise have not produced as consistent results as have studies of highway noise (8). They do, however, clarify some of the acute data-collection problems encountered in attempting to relate noise levels to property values and also point to another analytical method. Plowden and Sinnott (9) identify three major problems with data for such studies. The first is to find comparable housing for which recent sales are known, the second is to ensure that the homes are subjected to different noise levels, and the third is to interpret the data correctly. Although the problems are more difficult in studies of aircraft noise, they apply as well to studies of highway noise.

The obvious way to overcome these difficulties in studies of highway noise is to choose sites for analysis that consist of parallel rows of identical housing where the first row is adjacent to a major arterial roadway or a limited-access expressway. The parallel rows of housing at each site provide uniform sound-level characteristics within each row, and the identical housing ensures that any differences in price are caused by proximity to the highway. Analysis of variance can then identify the significance of such differences in price.

The data collection for this analysis was undertaken with analysis of variance primarily in mind. The criteria for site selection resulted in restriction of the size of potential sites, and the number of sales at each site turned out to be relatively small. In addition, it proved difficult to control for housing characteristics as closely as we wished. Therefore, the analysis reported here is based primarily on a number of multiple regressions augmented by the results of an analysis of variance.

SITE SELECTION AND DATA COLLECTION

Initially, 14 potential sites were identified. These resulted from field observations and met the criteria mentioned earlier—that is, each consisted of parallel rows of very similar housing adjacent to a major road. Information on the successful sale of any home in each area from 1975 to June 1977 was obtained from multiple listing sources through the cooperation of two local real estate offices. Sales before 1975 were not considered because of the rapid increase in housing prices in 1973 and 1974, which would tend to obscure the effect of any other variable. By 1975, housing prices had stabilized; this provided 2.5 years of data. Because of insufficient sales in different rows at half the sites, only 6 of the potential sites could be used in this investigation (Table 1). This confirms half of Plowden and Sinnott's first warning on finding sufficient recent sales (9). There were a total of 88 sales at the 6 sites but, because of the incompleteness of the data sources, not all of the housing characteristics were available for all of the sales.

Information on the sound levels at each site was collected by using either a BBN model 614 community noise monitor or a DA603A monitor. The monitor was located to approximate the closest face of the dwelling to the major roadway on each row of housing. The monitors were left in place for a 24-h weekday period. In keeping with the practice of the Ontario Ministry of the Environment, one of the project sponsors, the sound levels have been reduced to three periods of the day: daytime (7:00 a.m. to 7:00 p.m.), evening (7:00 to 11:00 p.m.), and night (11:00 p.m. to 7:00 a.m.). For simplicity, only the average sound level (L_{eq}) has been reported for each period, as follows:

	L_{eq} [dB(A)]		
Site	7:00 a.m.- 7:00 p.m.	7:00- 11:00 p.m.	11:00 p.m.- 7:00 a.m.
1	76	73	73
2	67	65	61
3	65	64	58
4	70	65	63
5	69	68	67
6	73	70	67

ANALYTICAL RESULTS

The initial approach for analyzing these data was based on an analysis of variance of the selling price of the housing for each site. Had the site selection been more successful in achieving comparable housing within each site, this approach alone might have been sufficient. However, almost all sites had at least one housing characteristic that differed between the rows of housing (Table 2). At several sites, this turns out not to complicate the interpretation of results; at others it does. For this reason, multiple regression analysis was used in the statistical analysis, and the data in Table 2 were

Table 1. Description of six sites used in the analysis.

Site	City	Location	Source of Noise	Type of Housing	Number of Total Sales (1975-1977)
1	Mississauga	South Service Road and Exbury Crescent	Queen Elizabeth Way	Single-family	16
2	Mississauga	Grassfire Crescent	Dixie Road	Single-family	12
3	Mississauga	Flamewood Drive	Burnhamthorpe Road	Town-houses	9
4	Burlington	Palmer Drive	Guelph Line	Town-houses	25
5	Ancaster	Hatton Drive, Enmore Avenue, and Calvin Street	Highway 403	Single-family	15
6	Burlington	Cloverleaf Drive, Glen View Avenue, and Marley Crescent	Queen Elizabeth Way	Single-family	11

Table 2. Average housing characteristics at each site by row.

						Number of Houses With			
Site	Row	Number of Rooms	Number of Bathrooms	Size of Garage (number of automobiles)	Percentage With Pool	No Basement	Unfinished Basement	Partially Finished Basement	Fully Finished Basement
1	1	6	2	1	0				3
	2	5.9	1.25	0.63	0				5
2	1	7.2	2.0	2.0	17		1	1	3
	2	8.0	2.84	2.0	33		1		3
3	1	6.0	2.0	1.0	0			1	3
	2	6.0	2.0	1.0	0				3
4	1	6.4	2	1	0				2
	2	8.0	2	1	0				3
	3	6.0	2	1	0				4
5	1	7.3	1.7	0.33	0				3
	2	6.0	1.0	0.5	0			1	1
	3	5.0	1.0	1.0	0				1
6	1	5.5	1.25	0.25	0				3
	2	7.0	1.25	1.0	26				4

used only qualitatively to help direct the regression analysis.

The analysis of variance shows that at two of the six sites there is a significant difference in the selling price:

Site	Row	Selling Price Average ($)	Standard Deviation ($)	Significance of Differences
1	1	56 750	1 475	0.017
	2	60 600	3 247	
2	1	90 900	16 690	0.365
	2	99 333	14 010	
3	1	51 700	3 421	0.624
	2	50 625	2 689	
4	1	42 767	1 979	
	2	43 717	881	0.686
	3	43 823	1 993	
5	1	54 810	4 615	
	2	54 271	8 652	0.503
	3	49 333	289	
6	1	50 000	4 619	0.001
	2	64 543	4 779	

At site 1, the first row of housing sold for an average of $3850 less than the second row, or roughly 7 percent of the first-row price. The difference in sound level between the two rows is quite large [14 dB(A) in daytime L_{eq}), and the level at the first row [76 dB(A) in daytime and 73 dB(A) at nighttime] is close to the maximum that one is likely to encounter near normal highways. At site 6, the first row of housing sold for an average $14 543 less than the second row, or a 29 percent difference. However, at this site, three of the housing characteristics differ, and all indicate that the second row of housing is better than the first. Hence, it would be incorrect to assign all of that difference in housing price or even most of it to the difference in the noise environment of the two rows. Since, however, the sound levels differ by roughly 10 dB(A) and the level at the first row is nearly as high as at site 1, it is plausible that noise is also a contributing factor to the difference in price.

At the remaining four sites, any existing differences in average housing prices are not significant at the 0.05 level. This absence of a difference may provide further information about the occurrence of differences in housing prices attributable to road traffic noise. In particular, at all four sites that do not show significant differences, the daytime L_{eq} is 70 dB(A) or less at the first row of housing. At the two sites that do show price differences, the daytime L_{eq} is 73 or greater.

Table 3. Multiple regression results for sites that experience 70-dB(A) daytime L_{eq}.

Variable	All Variables in Set: Coefficient[a]	Standard Error	Order of Entry	Four Variables Only: Coefficient	Standard Error	Order of Entry
Daytime L_{eq}	-729	104	1	-658	89	1
Number of rooms	-	-		-	-	
Number of bathrooms	7864	1342	2	7252	1116	2
Size of garage	-	-		-	-	
Presence of swimming pool	9332	2362	3	9739	2266	3
Year of sale	2554	823	4	2325	768	4

[a] Reported only for variables significant in the equation at the 0.05 level or better.

The possibility of a threshold noise level below which the price of housing is unaffected suggests that in performing multiple regression analyses it may be useful to separate the sites on the basis of the noise level experienced.

One difficulty in analyzing factors that affect housing prices is that relative location within a metropolitan area clearly has a significant effect; there is in fact a large body of literature on this factor alone (10). The seven sites in this study, as indeed the four sites reported in the study by Gamble, Sauerlender, and Langley (6), are widely dispersed throughout the area. To control for the location price, all regression results reported here use as the dependent variable the difference between the selling price of a house and the average selling price for all houses at that site. If some such technique is not used, combining data from all sites is likely to yield misleading results.

The difference in price was regressed against the L_{eq} and the following housing characteristics: number of rooms, number of bathrooms, garage size (number of automobiles), and presence of a swimming pool (included as a dummy variable). Information on the condition of the basement had been obtained during data collection but could not be used directly in this analysis because it is only ordinal data. Length and width of the lot were not included in the analysis partly because of a high proportion of missing data, which would have reduced the sample severely, and partly because of the high degree of correlation of these variables with number of rooms for those cases in which data were available. To be sure that there were no major shifts in prices over the 2.5-year period, the final variable used in the analysis was the year of the sale. Subsequent work with these data will use constant-dollar prices.

The data were analyzed in two subsets—as suggested by the results of the analysis of variance—as well as in the entire set. The first subset consisted of the two noisy sites, which contained a total of 27 house sales. Clearly, this is a very small data set for multiple regression, and underlying relations must be fairly strong to be identified as significant. Because values were missing for some variables, the actual number of cases available for regression is even smaller. A second analysis, restricted to those variables that were significant at the 0.05 level in the first regression, was performed to see if coefficients remained stable with an increased number of data points. The results of the analyses are given in detail in Table 3 and can be summarized as follows:

Subset	Number of Cases	Multiple R	Adjusted R^2
All variables in set	15	0.949 66	0.862 59
Four variables only	21	0.931 70	0.835 07

For the noisy sites, inclusion of all variables provides only 15 data points, but the resulting adjusted R^2 is 0.86, and the overall equation is significant (F) at the 0.0001 level (Table 3). The absence of the number of rooms from the equation seems attributable primarily to the low variation in this variable. Noise is valued at just over $700/dB—a value that is higher than that at any site in the paper by Gamble, Sauerlender, and Langley (6). Restriction of the analysis to the four significant variables in this first equation (Table 3) increases the number of cases to 21, which has the effect of altering all the coefficients and slightly reducing the R^2. However, the new coefficients are all within one standard deviation of the old ones, so they are in no sense contradictory, and for all coefficients the standard error has decreased. The new value for the noise effect is just over \$650/dB. It should be emphasized that this value applies only to the noisy sites—that is, 73 to 76 dB(A) in daytime L_{eq}.

The implications of these regression parameters are most easily demonstrated for site 1. A difference of 14 dB(A) between rows implies roughly a \$10 000 difference in housing prices. The actual difference is only \$4000. However, houses in the second row have an average 0.75 fewer bathrooms. Since these appear to be valued at close to \$8000, the \$6000 discrepancy is accounted for. Another interpretation is that construction of a barrier that causes a 15-dB(A) reduction in L_{eq} probably increases the value of the adjacent property by close to \$10 000. At noisy sites, it seems clear that traffic noise can make a sizable difference in housing prices.

At the remaining sites, which experience 70 dB(A) or less daytime L_{eq}, no such effect is apparent. The noise measure is the last of the six variables to enter the equation and is significant at only the 0.61 level. In fact, none of the variables are significant at the 0.05 level, and the adjusted R^2 indicates that the full set of variables explains less than 10 percent of the variation in price differences from each site's average; thus, these results are not given in a table. (Of the 61 possible sales, only 30 have full data for this analysis.) The reason for this poor result appears to be the importance of the basement variable in this subset. Allowing it to be used in an exploratory regression (which is not valid because basement condition is only an ordinal-level variable) shows it to be the first variable entered and results in two other variables being significant at the 0.05 level in a multivariate equation and the adjusted R^2 being 0.49. The noise measure is still not significant, however. It would be the fourth variable entered, but its coefficient in the four-variable equation is only 154 with a standard error of 216.

In an effort to improve the regression for these less noisy sites and to emphasize the noise variable, site 2 was deleted from the analysis. It has the smallest difference in noise levels between rows [only 6 dB(A) as opposed to more than 10 dB(A) at the other 3 sites] and the largest variation in prices as well as much higher prices overall. The remaining three sites (3, 4, and 5) seemed more nearly comparable. For this subset of the data, 20 cases were usable. A three-variable equation (size of garage, number of bathrooms, and year of sale) explains 55 percent of the variation, and all three variables are significant in the equation. The next variable to enter is the pseudo-variable on basement condition, which brings the adjusted R^2 up to 0.76. The noise measure enters next but does not increase the R^2 and has a coefficient of only 28 with a standard error of 50, so it is clearly not significant. Noise level does not appear to affect housing prices significantly when the daytime L_{eq} is below 70 dB(A) even where a 10-dB(A) difference exists between rows of housing.

Analyzing all of the sites together can be expected to mask these two separate effects and to show a lower average price per decibel than the first subset did, and this does indeed happen. For the set of variables that excludes basement condition, the noise measure is the last variable to enter and is significant only at the 20 percent level: The coefficient is only 187 with a standard deviation of 140. For this equation, with all variables entered, the adjusted R^2 is only 0.22, which suggests that basement condition remains important for the full data set. When basement condition is added to the set of variables, it is the first variable to enter, and the final adjusted R^2 for all variables increases to 0.50. Clearly, it would help the explanatory value of these equations if a valid interval-level measure of basement condition were available. Several efforts were made to provide this, at least as a dummy (0, 1) variable (since all houses had basements and almost all were finished) by deleting two or three cases and by dichotomizing to totally finished and not totally finished. These produce valid regressions in which basement condition is always among the first three variables to enter and in which the adjusted R^2 ranges from 0.43 to 0.60. However, the important point is that, in all analyses with the full data set, the place of the noise variable changes little. It is usually the fourth variable entered but is only significant at about the 16 percent level. Its coefficient is similar in most instances—in the 170s—and the standard error is in the 120s or 130s. Clearly, then, this combination of data from sites that experience a range of noise levels has obscured the strength of the effect of traffic noise on housing prices.

CONCLUSIONS

The principal conclusion of this analysis is that major differences in housing prices are clearly related to high levels of noise from highway traffic. Both parts of that statement must be emphasized. First, high sound levels—above 73-dB(A) daytime L_{eq} or higher, for example—are necessary if housing prices are to be significantly affected. Levels of 60 and 65 dB(A) have been shown to be associated with annoyance but appear not to affect housing prices. [A daytime L_{eq} of 70 dB(A) is approximately the level at which 50 percent of the population is disturbed by traffic noise (3).] Second, for these high noise levels, the cost of noise appears to be roughly \$650 to \$700/dB. A noise barrier that produces a 15-dB(A) reduction would be worth approximately \$10 000/housing unit.

Although these conclusions are fairly clear from the data presented here, two questions warrant consideration. Are the results consistent with earlier findings? Can one be sure that the differences in housing price are the result of noise?

The obvious results with which to compare for consistency are those of Gamble, Sauerlender, and Langley (6) for two reasons: The analytical approach was similar, and their results showed a considerable variation in the dollars-per-decibel value at the different sites. If that variation was related to noise levels, the results reported here would be strengthened. At first glance, their results do not support ours. The highest dollars-per-decibel value, 646, occurs at the lowest noise pollution level (NPL), 80 dB(A). The other three sites have NPL readings over 85 and dollars-per-decibel values of less than 150. However, the noise measure used in that study is not directly comparable with that used here. The NPL adds a factor, related to variability, to the L_{eq} (11), which gives added weight to sites with intermittent noisy events. There is a strong possibility that the choice of NPL as the noise measure has obscured the result we have found and that it is present in the data of Gamble, Sauerlender, and Langley as well. If one looks at their site descriptions, it is at least plausible that the site with the highest dollar-per-decibel value has the highest L_{eq}. The percentage of trucks is double that at the sites with similar traffic volumes, which would increase the L_{eq} and reduce the variability. Consequently, it is not clear at the moment whether their results do or do not support our conclusions.

The second question receives a more definite answer that likewise leaves our results a bit tentative. One cannot be sure that the differences in housing price associated with traffic noise are in fact caused by the noise. They may be caused by several other factors, such as air pollution or dust. Because noise is a good correlate of distance from the highway, it serves as a proxy for these variables as well. Gamble, Sauerlender, and Langley (6) point out the difficulties of isolating these several effects of road traffic. Rather than undertaking the extensive data collection that would be necessary to provide sufficient data to isolate such factors, it may be more practical simply to study the economic consequences of the construction of noise barriers along very noisy stretches of road. If they are associated with differences in housing prices of the magnitude we have identified, they are apparently effective in reducing whatever effects people are reacting to.

The results reported in this study have one very important implication for noise-abatement policies: Noise impacts, as expressed in house price differentials, are a nonlinear function of sound levels. Our results show these economic consequences to be not significantly different from zero at roughly 65 dB(A) daytime L_{eq}, and to be considerable ($650/dB) at daytime average sound levels in the mid-70s [dB(A)]. More data than were available for this study would be needed to specify the nature of the relation fully, but the nonlinearity of the impact is clear. Consequently, it is more important to achieve noise reduction at the noisiest locations than it is to achieve an equal reduction at locations that are not quite so noisy. Such a proposition has seemed intuitively reasonable to many people, but existing studies did not provide strong support for it. This analysis does support it and suggests that future research on differences in housing prices should focus on locations that experience 70-dB(A) (daytime L_{eq}).

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