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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 ($\underline{3}$, $\underline{4}$, $\underline{5}$, $\underline{6}$, $\underline{7}$, $\underline{8}$).

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 ($\underline{9}$, $\underline{10}$, $\underline{11}$); i.e.,

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

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:

$$QOL_{jt}^s = g[EC(H, EX), ED(H, EX), SE(H, EX), MA(H, EX)] \qquad (2)$$

$$QOL_{jt}^c = h[EC(EX), ED(EX), SE(EX), MA(EX)] \qquad (3)$$

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

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

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,

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

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 | | | | | | Metropolitan Average |
		(S/C)1	(S/C)2	(S/C)3	(S/C)4	(S/C)5	(S/C)6	
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 ($dQOL^e_{jt}/dQOL^o_{jt}$).

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.

ACKNOWLEDGMENTS

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