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Abridgment

Establishing Priorities for the Location of Transit Stations for Development Purposes

Ronald G. Arbogast, Snehamay Khasnabis, and Kenneth S. Opiela

The feasibility of an objective approach for prioritizing transit station locations for development purposes based on socioeconomic and land use indicators is examined. The Detroit metropolitan area was used as the experimental site for such feasibility testing. Two priority ranking methodologies were developed based on the provisions of the rating and ranking methods. Station development potential was identified by a set of socioeconomic and land use indicators, and the viewpoints of local professionals were solicited in assessing the relative importance of these indicators. Next, the relative rankings for 37 proposed transit stations on two travel corridors were developed by using the indicators and the viewpoints of local professionals. The results suggest that it is possible to prioritize station locations for joint development based on selected socioeconomic and land use indicators. The results also suggest that the station ranks obtained by the two methods are not likely to be affected by input solicited from local professionals. The procedures developed were found to be sensitive to the selection of the indicators.

An increasing emphasis on public transportation in the United States is providing new opportunities for transit and land use coordination through the application of the joint-development concept. A number of large cities in this country—notably, Atlanta, Baltimore, Detroit, Miami, San Francisco, and Washington, D.C.—have been forerunners in long-range transit planning. The stations on these cities' systems, which represent nodes of high accessibility, are considered to be prime candidates for the application of the joint-development concept. Joint-development projects can be used to promote multiple use of station sites and encourage high-density land uses as well as to provide direct access to the transit facility. Such coordinated planning is necessary to integrate new development projects into the fabric of the station environment, to the mutual benefit of the community, the transit agency, and the private sector.

Research in the area of station planning supports this joint-development concept. In 1971, the U.S. Department of Housing and Urban Development and the U.S. Department of Transportation sponsored a study to identify potentials and constraints for such an approach in transit planning. The study (1) was conducted by the National League of Cities and the U.S. Conference of Mayors. It concluded that, although the concept of joint development has not often been applied to promote urban development in this country, there are potential uses for this approach in transit station planning. Research by others (2-6) offers support for the benefits of coordinated development. Our own more recent research (7) analyzed adoption of the joint planning approach in transit station projects in the Detroit metropolitan area.

STATEMENT OF THE PROBLEM

The current level of planning and research activities clearly supports the concept of coordinating land development during station planning. However, a number of questions emerge as critical issues that must be satisfactorily resolved before public and private agencies commit themselves to development projects as called for in the joint planning approach. These questions arise from the apparent lack of an objective technique by which to identify station areas where such joint projects should be planned. Station location decisions on any proposed system are typically made early in the planning phase. Although all proposed stations may be candidates for such joint planning, limited monetary resources often dictate that only a few station sites be considered for such purposes. The questions that must be answered initially during the planning process are

1. What makes one station site more attractive than others so as to warrant the joint investment of public and private funds in development projects?
2. Is it possible to identify indicators of development potential for station area sites based on existing data sources?
3. Is it possible to incorporate the viewpoints of local professionals in such a process of site identification?

This paper describes the development and application of a priority analysis methodology for identifying station sites for joint projects based on a set of prespecified indicators. The developed methodology was applied to a proposed set of 37 light rail transit stations established in the Woodward and Gratiot travel corridors in the Detroit metropolitan area. The specific objectives of the research reported in this paper are

1. To develop an objective approach for prioritizing station locations for development purposes, based on a set of socioeconomic and land use indicators;
2. To elicit the viewpoints of local planners, engineers, and developers in assessing the relative importance of the indicators identified; and
3. To compare the development potentials of travel corridors based on an aggregation of priority scores contained in a given corridor.

RESEARCH METHODOLOGY

An empirically based methodology was developed to prioritize proposed transit station locations on the basis of development potential. The term development potential refers to the tendency of the station area to foster development projects. This potential can conceivably be measured by a number of indicators that identify the environmental characteristics—e.g., socioeconomic and land use conditions—of the station areas.

Methodological Approach

Two priority ranking methodologies were structured to determine the development potential of station locations for a proposed system: Method 1 is called raw-data priority ranking, and method 2 is called Z-score priority ranking. Both methodologies were developed to incorporate weighting schemes based on the use of professional preferences.

Raw-Data Priority Ranking

A total of k indicators for each of the n stations were aggregated to produce station rankings. The following mathematical expressions are used for this ranking. For the unweighted score (station ranking with respect to each indicator),

$$S_i = \sum_{j=1}^{k} V_{ij} \quad \text{for } i = 1 \text{ to } n \tag{1}$$

For the weighted score (station ranking and indicator weighting),

$$S_i = \sum_{j=1}^{k} W_j V_{ij} \quad \text{for } i = 1 \text{ to } n \tag{2}$$

where

S_i = priority ranking score for station i,
V_{ij} = rating value of indicator j for station i, and
W_j = weighted index for indicator j.

Z-Score Priority Ranking

The indicator data for each station were first converted to standardized Z-scores or standard normal deviates. The Z-scores were then aggregated over indicators for each station directly in both unweighted and weighted schemes to establish a measure of station rank. The following mathematical expressions are used for this ranking. For the unweighted score (Z-score summation),

$$S_i = \sum_{j=1}^{k} Z_{ij} \quad \text{for } i = 1 \text{ to } n \tag{3}$$

For the weighted score (Z-score summation and indicator weighting),

$$S_i = \sum_{j=1}^{k} W_j Z_{ij} \quad \text{for } i = 1 \text{ to } n \tag{4}$$

where Z_{ij} = standardized value of indicator j for station i.

Indicator Weighting

A procedure of weighting the indicator data (as denoted by W_j) was established to incorporate the professional viewpoint. Each of the indicators was rated on a 1-10 ascending scale by a group of 45 local planners, engineers, and developers involved in transit planning activity in the Detroit area. The mean rating of each indicator was used as a weighted index to signify its subjective degree of relative importance.

Sensitivity Analysis

Two separate sets of analyses were conducted with two sets of indicator data to test the sensitivity of the priority methodologies to the indicators used. A total of 13 indicators were used in the first analysis set; the data base in the second set was reduced to 7 indicators by selectively eliminating 6 indicators that were considered less important. The elimination was performed by using the coefficient of variation (CV) of the response data. The CV, which is the standard deviation of a variable expressed as a percentage of its mean, is a useful measure for comparing relative variation in the distribution of several data sets. The indicators that had a relatively higher CV were eliminated from the analysis for the purpose of the sensitivity analysis.

PREPARATION OF INPUT DATA

The selection of indicators for the priority analyses was based on viewpoints and suggestions from local professionals, review of past transportation studies, and the consideration of such constraints as data availability, research funding, and time limitations. Data sources were (a) the 1970 census summary tapes, (b) a 1965 transportation and land use study conducted for the Detroit area, and (c) a number of other reports. The resulting data base, which consisted of measures for a large number of variables, was defined for 168 census tracts contained in the two transit corridors in the study area.

Sixteen variables were selected from the original data base a priori as being potential indicators on the basis of their ability to describe the environment of a transit station location. This data set was transformed to represent the composite indicator values in percentage or density terms for the impact areas of each of the locations. The impact area was defined as the geographic area within a radius of 762 m (2500 ft) of a proposed station location (4). Two additional indicators, which represent projected transit ridership and volume of vehicle traffic for each station area, were added to the data set to make a total of 18 indicators.

A correlation analysis was performed on the 18 indicators in an effort to avoid double counting. One of the indicators for each highly correlated pair was eliminated. A total of 13 indicators were finally defined as measuring the development potential for each of the 37 station impact areas. The data set thus developed was used to generate the V_{ij} and Z_{ij} values according to the underlying principles of the rating and ranking methods (8).

RESULTS

The application of the two ranking methods, each using two sets of indicator measures and two weighting schemes, resulted in a total of eight independent priority rankings for each station. Table 1 gives a complete summary of the station ranks that resulted from the application of the two priority methodologies and shows the sensitivity of the 13- and 7-indicator sets to station ranking. Recall that each of the eliminated indicators had a high CV, which signifies that the respondents were more indecisive about these indicators than about the remaining 7. The contribution of the eliminated indicators appears to be quite significant on the final ranking of the suburban stations and marginal for the central business district (CBD) stations.

Significance Tests

The Spearman rank correlation coefficient procedure was used to determine whether there is a significant difference between the relative rankings obtained by (a) method 1 and method 2, (b) the unweighted and weighted schemes, and (c) the 13-indicator set and the 7-indicator set. This test is a standard statistical technique frequently used to test the degree of association between two sets of rankings assigned on a number of test objects (stations, in this case).

A total of 12 Spearman rank correlation tests were conducted to test the significance of difference in ranking. Conceivably, the difference in rankings of the same station could be attributed to a number of factors, such as differences in the methods, the weighting schemes, the indicators used, or some combination of these factors. The rank pairs were selected so that only the ef-

Table 1. Station rankings derived from use of prioritizing methods and indicator sensitivity analysis.

			Ranking							
			13 Indicators				7 Indicators			
			Method 1		Method 2		Method 1		Method 2	
Corridor	Station	Area	UW	W	UW	W	UW	W	UW	W
Woodward	1	Suburban	1	4	1	2	23	36	37	37
	2	Suburban	6	14	4	9	19	28	27	26
	3	Suburban	10	25	13	21	21	32	32	32
	4	Suburban	11	27	21	31	21	33	34	34
	5	Suburban	11	28	19	28	20	31	31	31
	6	Suburban	13	32	18	26	20	30	30	30
	7	Suburban	16	35	25	29	19	29	28	28
	8	Suburban	17	36	30	34	18	27	26	27
	9	Urban fringe	11	22	14	14	14	20	22	21
	10	Urban fringe	17	30	35	30	13	18	18	18
	11	Urban fringe	18	37	37	37	16	23	25	25
	12	Urban fringe	16	31	36	36	13	19	21	22
	13	Urban fringe	11	18	23	19	8	14	11	12
	14	CBD	6	7	8	5	5	6	6	6
	15	CBD	7	6	16	8	3	5	5	5
	16	CBD	4	5	9	6	4	4	4	4
	17	CBD	8	9	15	10	6	7	7	7
	18	CBD	3	3	5	4	2	3	3	3
	19	CBD	3	2	3	3	2	2	2	2
	20	CBD	2	1	2	1	1	1	1	1
Gratiot	21	CBD	9	10	24	17	8	12	14	14
	22	CBD	9	12	22	15	10	15	15	15
	23	CBD	9	11	28	20	11	16	17	17
	24	CBD	12	19	29	23	8	10	12	11
	25	Urban fringe	13	20	34	27	8	11	13	13
	26	Urban fringe	12	17	26	16	7	9	8	8
	27	Urban fringe	12	15	31	22	7	8	10	10
	28	Urban fringe	14	26	33	35	14	21	23	23
	29	Urban fringe	9	16	17	13	12	17	16	16
	30	Urban fringe	5	8	6	7	9	13	9	9
	31	Suburban	6	13	7	11	15	22	20	20
	32	Suburban	9	24	12	18	17	26	24	24
	33	Suburban	6	21	11	24	18	27	29	29
	34	Suburban	10	23	10	12	17	24	19	19
	35	Suburban	12	29	20	25	21	32	33	33
	36	Suburban	15	34	27	33	22	35	36	36
	37	Suburban	16	33	32	32	22	34	35	35

Notes: UW = unweighted station ranks; W = weighted station ranks.
Stations with identical priority scores were assigned the same ranking; thus, ranks may not be from 1 to 37 in all exercises. Lower station rank signifies a more desirable station area.

fect on one factor at a time would be tested. The results of the rank correlation tests are given below:

Pair of Rankings Tested	Factors Unchanged for Pair of Rankings Tested	Spearman Rank Correlation Coefficient
Method 1 versus method 2	13-indicator set	
	Unweighted	0.889
	Weighted	0.905
	7-indicator set	
	Unweighted	0.987
	Weighted	0.988
Unweighted versus weighted	Method 1	
	13-indicator set	0.890
	7-indicator set	0.998
	Method 2	
	13-indicator set	0.852
	7-indicator set	0.999
13-indicator versus 7-indicator set	Method 1	
	Unweighted	0.397
	Weighted	0.700
	Method 2	
	Unweighted	0.217
	Weighted	0.606

The criterion for establishing a degree of association was selected as 0.80 to interpret the results. If the value was above 0.80, it was concluded that there was a high degree of association between the two separate rankings.

The table indicates that

1. There is no significant difference between the relative station rankings obtained by using method 1 and method 2.
2. There is no significant difference between the relative rankings obtained by using the unweighted and weighted schemes.
3. There is a significant difference between the relative rankings obtained by using the 13-indicator set and the 7-indicator set.

Corridor-Level Analysis

The objective of the corridor-level analysis was to investigate whether it is possible to make conclusions about the desirability of one of the two Detroit corridors based on the development potentials of the station locations contained in the corridors. The input to this analysis was the weighted station-area priority scores for the 13-indicator case for method 1.

The station-area priority scores for the two corridors (20 stations in Woodward and 17 in Gratiot) were used to develop a cumulative frequency distribution. The 90th percentile value of the distribution indicated that 90 percent of the stations in the two corridors received a score below this value. Conversely, only 10 percent of the stations exceeded this value, which indicates that, out of 37 stations, approximately 4 had a higher score. It was found that these 4 stations were contained in the Woodward corridor. It was similarly found that, of the 9 stations that exceeded the 75th percentile value, 8 were in the Woodward corridor. The distribution that exceeded the 50th percentile value appeared to be balanced in that there were a total of 10 and 9 stations in the Woodward and Gratiot corridors, respectively. At the lower end of the distribution, the Woodward corridor contained a large number of stations that had lower scores below the 25th percentile value.

Cumulative frequency distributions of the priority scores were developed for each corridor. The distributions of the priority scores for the two corridors were significantly different, and the Woodward corridor exhibited the greater variation. The two curves intersected at the 53rd percentile value, which shows that the stations in the Woodward corridor have a lower priority score below the 53rd percentile value and higher priority scores above this value.

The results of the corridor-level analysis signify that neither corridor can be selected as totally superior in the sense of having the most desirable stations based on development potential. Even though the Woodward corridor contains a number of station areas that have higher priority ranking scores, it also contains several at the lower end of the distribution. On the other hand, the priority scores for most of the stations in the Gratiot corridor are clustered around the mean value, which indicates a smaller variation in the distribution.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this study are the following:

1. The methods of raw-data priority ranking and Z-score priority ranking can be used to develop priority scores for transit stations by using the value of each indicator developed from socioeconomic, land use, and transportation data for station impact areas. Furthermore, these procedures allow incorporation of proposed input through a weighting scheme. The study failed, however, to show any significant differences between the rankings obtained by using weighted and unweighted schemes.
2. Both methods of priority ranking are sensitive to the selection of the indicators included in the priority analysis. The sensitivity analysis showed marked differences in the relative ranking of the stations conducted by using a total of 7 indicators in comparison with the original 13.
3. The Spearman rank correlation test did not indicate any significant differences in the relative ranking of the stations in an aggregate sense (i.e., considering all stations together) between method 1 and method 2 or between the weighting schemes. However, differences in ranking were observed at individual station levels.
4. Of the two methods discussed, method 1—raw-data priority ranking—appears to have more general applicability. The implicit assumption of normality of the data may make method 2 inapplicable under certain situations.

The methodologies developed in this study can be used by other cities to identify station locations that have high development potential. The data used in the study are obtainable in virtually all urban areas from census and other sources, and local professional input can be incorporated in the process. However, further refinements in the process may make the methodology more effective as a general evaluation tool for application in other areas. Specifically,

1. Station impact boundaries need further clarification.
2. Since two basic methods have been used thus far, further efforts are needed to validate the most appropriate method.
3. Only data that represent a static environment have been used, but data that define modifications or trends with respect to time may be deemed important.
4. The feasibility of using other variables in the indicator set should be tested to take into account other factors that may more realistically reflect development potential.
5. The sensitivity of the procedure should be tested with regard to evaluating the desirability of different types of development packages.

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Use of a Multiregional Variable Input-Output Model to Analyze Economic Impacts of Transportation Costs

Chong K. Liew and Chung J. Liew

A multiregional variable input-output model is introduced to investigate the impact of a change in transportation costs on regional development and trade flows. Regional technical coefficients and trade coefficients are endogenous variables to the model and are sensitive to transportation costs as well as other input costs. Each industry is assumed to have a linear logarithm production frontier with a constant return to scale. Profit-maximizing price frontiers are obtained from the dual relation. These prices are expressed in terms of transportation costs, wage rates, land prices, input elasticities, and parameters of technical progress. These prices determine the regional technical coefficients and trade coefficients. The impact of a change in transportation costs on trade structure, regional growth, and inflation is investigated by using 1963 three-region, 10-sector interindustry flow data as a base. As expected, an increase in transportation cost between regions reduces the trade coefficient between the regions and increases the "own" trade coefficient; i.e., the purchases from other regions decrease and the purchases from local markets increase as the costs of transportation increase. An increase in transportation cost hampers regional development, but its sensitivity differs among industries.

Transportation cost plays a crucial role in determining regional development and trade flows. A lower transportation cost increases the trade flows among regions and contributes to regional development. A higher transportation cost reduces trade flows and deters regional development. An improvement in transportation facilities, such as the construction of highways, waterways, and railways, stimulates regional economic development and interregional trade flows, since such improvement reduces transportation cost. Impacts of an energy crisis, such as an increase in motor fuel costs, hamper regional growth and impede regional trade.

The U.S. Army Engineer Institute for Water Resources (IWR) is conducting an evaluation of the regional social, economic, and environmental effects of the McClellan-Kerr Arkansas River System project. That project, one of the major U.S. river basin developments, was dedicated in early 1971. The system provides navigation, flood damage reduction, hydroelectric power, water supply, and recreation for a large part of Arkansas and Oklahoma. At the same time that the navigation project was being built, an Interstate and toll-road system was developed that parallels the waterway and improves truck access. One of the significant problems in measuring the impact of such a system is determining the influence of lowered transport costs, attributable to the waterway, on regional economic development.

The research reported in this paper is directed toward developing an impact model that will show the with-project and without-project impacts of such a waterway.

LITERATURE REVIEW

Several models identify the relationship between the cost of transportation and regional development. One of the models that has successfully related transportation cost to regional development is Harris' multiregional, multi-industry forecasting model (1, 2). The Harris model forecasts industrial outputs, employment, income, consumer expenditures, government spending, and population in 173 Bureau of Economic Analysis (BEA) economic regions and identifies industrial locations. The model introduces marginal transportation costs to explain those endogenous variables. Transportation costs enter the model with other factor costs such as wage rates, land costs, and capital costs. Marginal transportation cost is calculated by a linear programming transportation algorithm. The model identifies industrial locations in each region when there is a change in transportation costs among regions.

However, like many other regional econometric models, a paucity of regional data in the Harris model compels the model builder to choose explanatory variables that have the same trend as the dependent variables, e.g., lagged dependent variables. A long-run economic impact analysis requires stability in the estimated coefficients, and the Harris model appears to lack such stability (the model must reestimate the coefficients each year, since they vary over time). The model also fails to identify the cross-hauling of commodity trade among regions.

Other popular approaches to relating trade flows to regional development are multiregional input-output models (3-6). These models are popular tools for forecasting regional trade flows and developments. The major drawbacks of the multiregional input-output models are their assumptions on fixed technical coefficients and fixed trade structure. They fail to allow the trade coefficients and the technical coefficients to vary over time in response to change in transportation costs, wage rates, land prices, and capital costs.

Amano and Fujita (7) have modified the multiregional input-output model and traced the regional and national economic impact of improvements in transportation facilities. Their basic hypothesis is that improvement of a transportation facility lowers both the monetary and nonmonetary costs of transportation. The lower costs change the transportation service purchase coefficients and the trade coefficients. Such change would affect regional outputs and trade flows. The model assumes that only one row of technical coefficients—namely, the transportation service purchase coefficients—depend on the cost of transportation and all other technical coefficients remain unchanged. The model also assumes that only the trade coefficients between the two regions where transportation costs were changed are affected by the cost change and all other trade coefficients remain unchanged. It further assumes that the trade and technical coefficients are independent of a change in wage rates, land prices, local tax structure, and capital costs.

Our basic hypothesis is that firms choose inputs from each region so as to minimize costs and sell their products to each region and thus maximize their profits. The technical coefficients and the trade coefficients are simply results of such optimizing behavior of firms. Therefore, any change in input cost should change all technical coefficients and all trade coefficients because the firms substitute less expensive inputs for expensive ones from each region. Transportation cost is one of the input costs, and any change in transportation cost should vary all technical and trade coefficients.

The multiregional variable input-output (MVIO) model described in this paper is derived from the basic duality between production and price possibility frontiers. From the dual relations, a set of price frontier equations is obtained. These prices in the frontier equations depend on input elasticities, transportation costs—both monetary and nonmonetary—wage rates, land prices, local tax rates, costs of capital goods, and parameters of technical progress. The equilibrium prices obtained from the price possibility frontiers affect the technical coefficients and the trade coefficients.

MULTIREGIONAL VARIABLE INPUT-OUTPUT MODEL

Consider an economy that has m regions and n commodities. Each industrial output in each region is assumed to be produced by a Cobb-Douglas production frontier:

$$\ln x_j^r - \alpha_{oj}^r - \sum_{s=1}^{m} \sum_{i=1}^{n} \alpha_{ij}^{sr} \ln x_{ij}^{sr} - \gamma_j^r \ln L_j^r - \delta_j^r \ln K_j^r = 0$$

$$(j = 1, \ldots, n; r = 1, \ldots, m) \qquad (1)$$

where

- x_j^r = output of industry j located in region r,
- x_{ij}^{sr} = intermediate purchase of the i th industrial output from region s by the j th industry located in region r,
- L_j^r = labor service employed by the j th industry located in region r, and
- K_j^r = service of capital employed by the j th industry located in region r.

α_{oj}^r, α_{ij}^{sr}, γ_j^r, and δ_j^r are parameters of the Cobb-Douglas production frontiers.

We assume linear homogeneity; namely,

$$\sum_{s=1}^{m} \sum_{i=1}^{n} \alpha_{ij}^{sr} + \gamma_j^r + \delta_j^r = 1 \qquad (j = 1, \ldots, n; r = 1, \ldots, m) \qquad (2)$$

The purchase price of input is defined as the sum of the price in the producing region and the transportation costs of delivering the input to the final purchaser. The transportation costs include line-haul cost and terminal cost. For example, the purchase price of the i th input from region s by the j th industry in region r (p_{ij}^{sr}) is the sum of the price of the i th good in producing region s (p_i^s) and the cost of transportation of delivering one unit of the i th good from region s to region r ($\mu_i^{sr} \cdot p_i^s$); i.e.,

$$p_{ij}^{sr} = (1 + \mu_i^{sr}) \cdot p_i^s \qquad (3)$$

The profit-maximizing input-output transformation functions are

$$-(f_j^r/f_{ij}^{sr}) = [(1 - t_j^r)\ p_j^r/c_i^{sr} p_i^s] \qquad (4)$$

$$-(f_j^r/f_{L_j}^r) = [(1 - t_j^r)\ p_j^r/w_j^r] \qquad (5)$$

and

$$-(f_j^r/f_{K_j}^r) = [(1 - t_j^r)\ p_j^r/v_j^r]$$

$$(i, j = 1, \ldots, n; r, s = 1, \ldots, m) \qquad (6)$$

where f_j^r, f_{ij}^{sr}, f_{Lj}^r, and f_{Kj}^r are the partial derivatives of the Cobb-Douglas production frontiers with respect to x_j^r, x_{ij}^{sr}, L_j, and K_j. p_j^r, w_j^r, and v_j^r are the price of the j th good, wage rate, and service price of capital in region r; t_j^r is the effective tax rate on the j th industry in region r; and c_i^{sr} is the unity plus the unit transportation costs; i.e.,

$$c_i^{sr} = (1 + \mu_i^{sr}) \qquad (i = 1, \ldots, n; s, r = 1, \ldots, m) \qquad (7)$$

From the input-output transformation functions (Equations 4-6), we derive the following profit-maximizing input demand equations:

$$x_{ij}^{sr} = \alpha_{ij}^{sr}\ (1 - t_j^r)\ p_j^r\ x_j^r/(c_i^{sr} p_i^s) \qquad (8)$$

$$L_j^r = \gamma_j^r\ (1 - t_j^r)\ p_j^r\ x_j^r/w_j^r \qquad (9)$$

$$K_j^r = \delta_j^r\ (1 - t_j^r)\ p_j^r\ x_j^r/v_j^r \qquad (10)$$

From Equations 1-10, we obtain multiregional price frontiers:

$$\ln p_j^r = -\sum_{s=1}^{m} \sum_{i=1}^{n} \alpha_{ij}^{sr} \ln[\alpha_{ij}^{sr}/(c_i^{sr} p_i^s)] - \alpha_{oj}^r$$
$$- \gamma_j^r \ln(\gamma_j^r/w_j^r) - \delta_j^r \ln(\delta_j^r/v_j^r) - \ln(1 - t_j^r)$$
$$= -\sum_{s=1}^{m} \sum_{i=1}^{n} \alpha_{ij}^{sr} \ln\alpha_{ij}^{sr} + \sum_{s=1}^{m} \sum_{i=1}^{n} \alpha_{ij}^{sr} \ln c_i^{sr} - \alpha_{oj}^r$$
$$+ \sum_{s=1}^{m} \sum_{i=1}^{n} \alpha_{ij}^{sr} \ln p_i^s - \gamma_j^r \ln\gamma_j^r + \gamma_j^r \ln w_j^r$$
$$- \delta_j^r \ln\delta_j^r + \delta_j^r \ln v_j^r - \ln(1 - t_j^r) \qquad (11)$$

Equation 11 can be conveniently stacked in the following matrix form:

$$(I - S) \ln p = h \qquad (12)$$

where

$$S = \begin{bmatrix} \alpha^{11} & \cdots & \alpha^{1m} \\ \vdots & \ddots & \vdots \\ \alpha^{m1} & \cdots & \alpha^{mm} \end{bmatrix}', \quad \ln p = \begin{bmatrix} \ln p^1 \\ \vdots \\ \ln p^m \end{bmatrix}, \quad h = \begin{bmatrix} h^1 \\ \vdots \\ h^m \end{bmatrix},$$

$$\alpha^{sr} = \begin{bmatrix} \alpha_{11}^{sr} & \cdots & \alpha_{1n}^{sr} \\ \vdots & \ddots & \vdots \\ \alpha_{n1}^{sr} & \cdots & \alpha_{nn}^{sr} \end{bmatrix}, \quad \ln p^r = \begin{bmatrix} \ln p_1^r \\ \vdots \\ \ln p_n^r \end{bmatrix}, \text{ and}$$

$$h^r = \begin{bmatrix} h_1^r \\ \vdots \\ h_n^r \end{bmatrix}.$$

$$h_j^r = -\left(\sum_{s=1}^{m} \sum_{i=1}^{n} \alpha_{ij}^{sr} \ln\alpha_{ij}^{sr} + \gamma_j^r \ln\gamma_j^r + \delta_j^r \ln\delta_j^r \right)$$
$$+ \gamma_j^r \ln w_j^r + \delta_j^r \ln v_j^r - \ln(1 - t_j^r) - \alpha_{oj}^r$$
$$+ \sum_{s=1}^{m} \sum_{i=1}^{n} \alpha_{rj}^{sr} \ln c_i^{sr} \qquad (13)$$

The prime (′) denotes a transpose, and I is an (n • m) by (n • m) identity matrix.

The transportation cost of delivering commodity i from region s to region r is assumed to be the same regardless of the type of buyer; i.e.,

$$c_{ij}^{sr} = c_i^{sr} \tag{14}$$

where $c_i^{sr} = 1$ if $s = r$ and $c_i^{sr} > 1$ if $s \neq r$.

The price frontiers are expressed in terms of the cost of transportation $[c_i^{sr} = (1 + \mu_i^{sr})]$, effective tax rates ($t_j^r$), local wage rates ($w_j^r$), service price of capital (v_j^r), input elasticities (α_{ij}^{sr}, γ_j^r, δ_j^r) and parameters of technical progress (α_{oj}^r).

In general, the profit-maximizing price level has a positive relation with the cost of transportation, effective tax rates, wage rates, and the service price of capital and a negative relation with parameters of technical progress. By jointly solving the price frontiers (Equation 12), we obtain (n·m) profit-maximizing price levels in terms of the cost of transportation, effective tax rates, local wage rates, service price of capital, input elasticities, and technical-progress parameters; i.e.,

$$p_j^r = p_j^r\,(c_i^{sr}, t_j^r, w_j^r, v_j^r, \alpha_{ij}^{sr}, \gamma_j^r, \delta_j^r, \alpha_{oj}^r) \tag{15}$$

From the profit-maximizing input demand equations, multiregional input-output coefficients are derived:

$$a_{ij}^{sr} = (x_{ij}^{sr}/x_j^r) = \alpha_{ij}^{sr}\,(1 - t_j^r)\,(p_j^r/c_i^{sr}\,p_i^s) \tag{16}$$

From Equations 15 and 16, we obtain the regional variable input-output coefficients, which are expressed in terms of transportation cost, effective tax rates, wage rates, service price of capital, input elasticities, and technical-progress parameters:

$$a_{ij}^{sr} = a_{ij}^{sr}\,(c_i^{sr}, t_j^r, w_j^r, v_j^r, \alpha_{ij}^{sr}, \gamma_j^r, \delta_j^r, \alpha_{oj}^r) \qquad (i, j = 1, \ldots, n;\ s, r = 1, \ldots, m) \tag{17}$$

The regional technical coefficients are the sum of the regional input-output coefficients over regions; i.e.,

$$a_{ij}^r = \sum_{s=1}^{m} a_{ij}^{sr} \qquad (i, j = 1, \ldots, n;\ r = 1, \ldots, m) \tag{18}$$

The regional input-output coefficients are calculated by multiplying the trade coefficients by the regional technical coefficients; i.e.,

$$a_{ij}^{sr} = t_{ij}^{sr} \cdot a_{ij}^r \tag{19}$$

From Equation 19, the following relations are evident:

$$t_{ij}^{sr} = a_{ij}^{sr}/a_{ij}^r \qquad (i, j = 1, \ldots, n;\ s, r = 1, \ldots, m) \tag{20}$$

Variable trade coefficients are obtained and are expressed in terms of transportation cost, primary input prices, tax rates, and input parameters from Equations 17, 18, and 20:

$$t_{ij}^{sr} = t_{ij}^{sr}\,(c_i^{sr}, t_j^r, w_j^r, v_j^r, \alpha_{ij}^{sr}, \gamma_j^r, \delta_j^r, \alpha_{oj}^r) \tag{21}$$

The average trade coefficients are estimated as follows:

$$t_i^{sr} = (1/n) \sum_{j=1}^{n} t_{ij}^{sr} \tag{22}$$

Following Moses (4), it is assumed that each industry in region r consumes the same fraction of the import of commodity i from region s, so that the trade coefficients (t_{ij}^{sr}) are the same regardless of the final users; i.e.,

$$t_{ij}^{sr} = t_i^{sr} \tag{23}$$

The average trade coefficients (t_i^{sr}) in Equation 22 are the Moses type of trade coefficients. In our model, they are endogenously determined from the basic duality of production and price frontiers.

Regional outputs x are determined by the usual balance equations:

$$x = (I - TA)^{-1}\,Ty \tag{24}$$

where

$$\underset{(nm,\,1)}{x} = \begin{bmatrix} x^1 \\ \vdots \\ x^m \end{bmatrix}; \qquad \underset{(nm,\,nm)}{T} = \begin{bmatrix} T^{11} & \cdots & T^{1m} \\ \vdots & \ddots & \vdots \\ T^{m1} & \cdots & T^{mm} \end{bmatrix};$$

$$\underset{(nm,\,nm)}{A} = \begin{bmatrix} A^1 & \cdots & 0 \\ & A^2 & \vdots \\ 0 & \cdots & A^m \end{bmatrix}; \qquad \underset{(nm,\,1)}{y} = \begin{bmatrix} y^1 \\ \vdots \\ y^m \end{bmatrix};$$

$$\underset{(n,\,1)}{x^r} = \begin{bmatrix} x_1^r \\ \vdots \\ x_n^r \end{bmatrix}; \qquad \underset{(n,\,n)}{T^{sr}} = \begin{bmatrix} T_1^{sr} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & T_n^{sr} \end{bmatrix};$$

$$\underset{(n,\,n)}{A^r} = \begin{bmatrix} A_{11}^r & \cdots & A_{1n}^r \\ \vdots & \ddots & \vdots \\ A_{n1}^r & \cdots & A_{nn} \end{bmatrix}; \text{ and}$$

$$\underset{(n,\,1)}{y^r} = \begin{bmatrix} y_1^r \\ \vdots \\ y_n^r \end{bmatrix}.$$

x and y are (n·m) components vectors of regional output and regional final demand, respectively. T and A are (n·m) by (n·m) matrices of trade coefficients and regional technical coefficients.

TRANSPORTATION COST SIMULATION MODEL

The MVIO model responds to firms' efforts to minimize their input costs. The transportation cost ($c_i^{sr} = 1 + \mu_i^{sr}$; $s, r = 1, \ldots, m$; $i = 1, \ldots, n$) is one of such input costs, besides wage rates, capital cost, and land cost, that the firms face in the local economy. A change in one such input cost results in changes in equilibrium outputs, prices, regional technical coefficients, trade coefficients, and various multipliers in all regions. Table 1 provides input parameters, exogenous variables, and endogenous variables. The exogenous variables are assumed to be determined outside of the model. The input parameters are assumed to remain unchanged. Endogenous variables are the dependent variables of the model.

We describe here, step by step, how a change in one of the exogenous variables affects the endogenous variables of the model. The initial impact of such a change affects the equilibrium prices in all regions. To show the relations between exogenous variables and price

Table 1. Input parameters and exogenous and endogenous variables in the MVIO model and other multiregional input-output models.

Model	Input Parameters	Variables: Exogenous	Variables: Endogenous
MVIO	Input elasticities Technical-progress parameters	Wage rates Service price of capital, including land costs and capital costs Costs of transportation Effective tax rates Final demands	Industrial outputs, income, and employment Industrial prices Regional technical coefficients and interindustry transactions Trade coefficients and interregional trade-flow matrices Various multipliers
Others	Regional technical coefficients Trade coefficients	Final demands	Industrial outputs, income, and employment Regional interindustry transactions Interregional trade flows

levels, the price-frontier equations are rewritten, as follows:

$$\ln p_j^r = g_j^r + \Sigma\Sigma\, \alpha_{ij}^{sr} \ln c_i^{sr} + \gamma_j^r \ln w_j^r + \delta_j^r \ln v_j^r - \ln(1 - t_j^r) + \Sigma\Sigma\, \alpha_{ij}^{sr}\, p_i^s \quad (25)$$

where

$$g_j^r = -\alpha_{oj}^r - \Sigma\Sigma\, \alpha_{ij}^{sr} \ln\alpha_{ij}^{sr} - \gamma_j^r \ln\gamma_j^r - \delta_j^r \ln\delta_j^r \quad (j = 1, \ldots, n;\ r = 1, \ldots, m) \quad (26)$$

Unless stated otherwise, $\Sigma\Sigma$ denotes $\sum_{s=1}^{m} \sum_{i=1}^{n}$.

The price-frontier equations are conveniently stacked in a matrix form:

$$(I - S) \ln p = g + W \cdot \ln c + \hat{\gamma}\ \ln w + \hat{\delta} \ln v - \ln(1 - t) \quad (27)$$

where

$$\underset{(nm,1)}{g} = \begin{bmatrix} g_1^1 \\ \cdot \\ \cdot \\ g_n^1 \\ \cdot \\ \cdot \\ g_n^m \end{bmatrix}; \qquad \underset{(nm,nmm)}{W} = \begin{bmatrix} S^1 & & & 0 \\ & S^2 & & \\ & & \ddots & \\ 0 & & & S^m \end{bmatrix};$$

$$\underset{(n,nm)}{S^r} = \begin{bmatrix} \alpha_{11}^{1r} \ldots \alpha_{n1}^{1r}, \ldots, \alpha_{11}^{mr} \ldots \alpha_{n1}^{mr} \\ \vdots \\ \alpha_{1n}^{1r} \ldots \alpha_{nn}^{1r}, \ldots, \alpha_{1n}^{mr} \ldots \alpha_{nn}^{mr} \end{bmatrix}; \qquad \underset{(nmm,1)}{\ln c} = \begin{bmatrix} \ln c_1^{11} \\ \cdot \\ \ln c_n^{11} \\ \cdot \\ \ln c_1^{mm} \\ \cdot \\ \ln c_n^{mm} \end{bmatrix};$$

$\underset{(mn,mn)}{\hat{\gamma}}$ = a diagonal matrix of γ_j^r;
$\underset{(mn,mn)}{\hat{\delta}}$ = a diagonal matrix of δ_j^r;
$\ln w$ = an (m·n) components vector of $\ln w_j^r$;
$\ln v$ = an (m·n) components vector of $\ln v_j^r$; and
$\ln(1 - t)$ = an (m·n) components vector of $\ln(1 - t_j^r)$.

The figure inside the parenthesis is the size of the matrix. The notation defined for the previous matrices is not defined here.

By taking a derivative of the price-frontier vector function (Equation 27) with respect to each cost vector, the relation between a change in cost variable and its impact on equilibrium prices is obtained:

$$\partial \ln p / \partial \ln c = [(I - S)^{-1}\, W]' \quad (28)$$

$$\partial \ln p / \partial \ln w = [(I - S)^{-1}\, \hat{\gamma}]' \quad (29)$$

$$\partial \ln p / \partial \ln v = [(I - S)^{-1}\, \hat{\delta}]' \quad (30)$$

$$\partial \ln p / \partial \ln(1 - t) = -[(I - S)^{-1}]' \quad (31)$$

The prime (′) denotes the transpose.

$[(I - S)^{-1}W)']$ is an (n·m·m) by (n·m) transportation-cost-related price multiplier. It explains a corresponding change in equilibrium prices in each industry in each region that results from a 1 percent change in c_i^{sr}, which is unity plus rate of transportation cost $(1 + \mu_i^{sr})$. The transportation-cost-related price multipliers explain every detail of the impact of a change in transportation cost on the industrial prices in all regions.

A change in the transportation cost for a single commodity between two regions could affect the equilibrium prices of all commodities in all regions. The same rate increase in transportation cost for two different commodities yields completely different price effects in all regions. From the policy point of view, this is very important. It implies that construction of a waterway in Oklahoma and Arkansas could affect the price of bread purchased by a New Yorker. The increase in motor fuel cost may have different price effects depending on which commodity is being shipped with the motor fuel. The transportation-cost-related price multipliers provide details of such interesting questions.

The right-hand expressions of Equations 29-31 are price multipliers related to wages, the service price of capital, and the tax rate. All regional economies are interrelated. A change in wages, the service price of capital, or tax rates affects not only the industrial prices of that region but also those of all other regions. These chain impacts are traceable by those price multipliers.

Next, we evaluate how the changed prices that result from a change in transportation cost, wage rate, service price of capital, or effective tax rate would affect the multiregional input-output coefficients. These coefficients are decomposed into regional technical coefficients and trade coefficients.

From Equation 16, the following relation is evident:

$$\ln a_{ij}^{sr} = \ln \alpha_{ij}^{sr} + \ln(1 - t_j^r) + \ln p_j^r - \ln c_i^{sr} - \ln p_i^s \quad (32)$$

Suppose that the transportation cost is the only change in the economy; the rate of change in multiregional input-output coefficients can easily be identified, as follows:

$$\partial \ln a_{ij}^{sr}/\partial \ln c_i^{sr} = (\partial \ln p_j^r/\partial \ln c_i^{sr}) - 1 - (\partial \ln p_i^s/\partial \ln c_i^{sr}) \quad (33)$$

or

$$\partial \ln a_{ij}^{sr} = \partial \ln p_j^r - \partial \ln c_i^{sr} - \partial \ln p_i^s \quad (34)$$

The right-hand expressions in Equation 33 are simply transportation-cost-related price multipliers obtained in Equation 28.

Suppose that we have base-year multiregional input-output coefficients $a_{ij}^{sr}(t_o)$; the new input-output coefficients after the change in transportation cost $[a_{ij}^{sr}(t_1)]$ can be evaluated as follows:

$$a_{ij}^{sr}(t_1) = a_{ij}^{sr}(t_0) \exp(\partial \ln p_j^r - \partial \ln c_i^{sr} - \partial \ln p_i^s) \quad (35)$$

Note that $\partial \ln a_{ij}^{sr}$ is approximated by $\ln a_{ij}^{sr}(t_1) - \ln a_{ij}^{sr}(t_o)$ or $\ln[a_{ij}^{sr}(t_1)/a_{ij}^{sr}(t_o)]$.

The change in wage rate, service price of capital, and effective tax rate is traced in a similar way:

$$\partial \ln a_{ij}^{sr}/\partial \ln w_j^r = (\partial \ln p_j^r/\partial \ln w_j^r) - (\partial \ln p_i^s/\partial \ln w_j^r) \quad (36)$$

$$\partial \ln a_{ij}^{sr}/\partial \ln v_j^r = (\partial \ln p_j^r/\partial \ln v_j^r) - (\partial \ln p_i^s/\partial \ln v_j^r) \quad (37)$$

$$\partial \ln a_{ij}^{sr}/\partial \ln(1 - t_j^r) = [\partial \ln p_j^r/\partial \ln(1 - t_j^r)] + 1 - [\partial \ln p_i^s \div \partial \ln(1 - t_j^r)] \quad (38)$$

These multiregional input-output coefficients (a_{ij}^{sr}) decompose into the regional technical coefficients a_{ij}^r and trade coefficients t_i^{sr}, as explained in Equations 18-22.

EMPIRICAL FINDINGS

The variable input-output model responds to the optimizing behavior of firms in response to a change in input costs. Transportation costs, wage rates, and the service price of capital are important input costs to business firms. The service price of capital includes land cost and capital cost. Any change in these input costs affects firms' decisions on input demands and output prices. In this process, regional technical coefficients, trade coefficients, industrial growth, and regional inflation are changed.

The effect of a change in transportation costs on regional development and trade structures can be investigated by using 1963 interregional commodity flow data.

The U.S. Army Corps of Engineers system of regional classification divides the U.S. economy into three regions: (a) region 1—the Arkansas navigation region, which is a combination of Office of Business Economics (OBE) areas 117-119; (b) region 2—the west-south-central region (excluding region 1), which includes Texas, Louisiana, Arkansas, and Oklahoma; and (c) region 3—the rest of the United States.

U.S. industries are aggregated into 10 industrial sectors:

1. Agriculture, forestry, and fisheries;
2. Mining;
3. Construction;
4. Nondurable manufacturing;
5. Durable manufacturing;
6. Transportation, communication, and utilities;
7. Wholesale and retail trade;
8. Finance, insurance, and real estate;
9. Service; and
10. Federal, state, and local government.

The 1963 three-region, 10-sector interregional transaction table compiled by Kim (8) was used as the base-year data for this study.

A 5 percent change in transportation cost is introduced (a) between regions 1 and 2 (no change in transportation cost between regions 2 and 3 or regions 1 and 3), (b) simultaneously between regions 1 and 2 and regions 1 and 3 (no change between regions 2 and 3), and (c) among all three regions. The transportation cost is assumed to have changed for both delivering and receiving the commodities of the following industries: (a) agriculture, forestry, and fisheries; (b) mining; (c) nondurable manufacturing; (d) durable manufacturing; (e) finance, insurance, and real estate; and (f) service industries.

A 5 percent decrease in the cost of transportation between regions 1 and 2 substantially increases trade between these two regions. The percentages of goods imported by each of these two regions from the other, before and after the cost decrease, are given below:

	Percentage of Goods Imported			
	Region 1		Region 2	
Industry	Before	After	Before	After
Agriculture, forestry, and fisheries	33.68	34.73	5.05	5.35
Mining	61.87	62.78	1.25	1.32
Nondurable manufacturing	31.78	32.79	4.01	4.26
Durable manufacturing	19.95	20.76	3.78	3.99

The expansion of trade between regions 1 and 2 makes both regions reduce their industrial consumption of locally produced goods and their imports from region 3. This occurs because the cost to regions 1 and 2 of delivering and receiving goods from region 3 becomes relatively expensive, since it is assumed that there is no change in transportation cost between either regions 1 and 3 or regions 2 and 3 and only the transportation cost between regions 1 and 2 has changed.

When transportation costs were reduced between regions 1 and 2 and regions 1 and 3 at the same time, the trade coefficients of each region were lowered in all three regions. This implies that each region relies more on imports from other regions and less on locally produced goods. For example, in 1963, the "own" trade coefficients for nondurable manufacturing goods were 26.37 percent in region 1, 61.70 percent in region 2, and 94.22 percent in region 3. The own trade coefficient is the diagonal element of the trade-coefficient matrix. A 5 percent decrease in transportation costs between regions 1 and 2 reduces those own trade coefficients to 26.19 percent in region 1, 61.56 percent in region 2, and 94.20 percent in region 3. The simultaneous 5 percent decrease between regions 1 and 2 and regions 1 and 3 further reduces the own trade coefficients to 25.86 percent in region 1, 61.53 percent in region 2, and 94.16 percent in region 3. The 5 percent decrease among all three regions reduces these coefficients to 25.789 percent in region 1, 60.653 percent in region 2, and 93.878 percent in region 3. A decrease in own trade coefficients implies an increase in import coefficients—i.e., the off-diagonal coefficients of the trade-coefficient matrix. In general, the import coefficient has an inverse relation with the cost of transportation between two regions. Tables 2 and 3 give details of those changes for

Table 2. Trade coefficients of selected commodities before and after change in transportation cost.

Industry	Region	No Change (%) Region 1	Region 2	Region 3	5 Percent Decrease (%) Between Regions 1 and 2 Region 1	Region 2	Region 3	Between Regions 1 and 2 and 1 and 3 Region 1	Region 2	Region 3
Agriculture,	1	30.61	5.05	1.57	30.30	5.35	1.59	30.00	5.41	1.68
forestry, and	2	33.68	51.96	5.82	34.73	51.83	5.83	34.00	51.80	5.82
fisheries	3	35.71	42.99	92.61	34.98	42.82	92.59	36.00	42.80	92.50
Mining	1	17.44	1.25	0.89	16.91	1.32	0.90	16.87	1.32	0.95
	2	61.87	77.21	19.65	62.78	77.15	19.66	62.36	77.15	19.65
	3	10.69	11.55	69.45	10.31	11.53	69.44	10.77	11.53	69.41
Nondurable	1	26.37	4.01	0.72	26.19	4.26	0.73	25.86	4.31	0.77
manufac-	2	31.78	61.70	5.06	32.79	61.56	5.07	32.02	61.53	5.07
turing	3	41.85	34.29	94.22	41.02	34.17	94.20	42.12	34.16	94.16
Durable manu-	1	18.27	3.78	0.91	18.18	3.99	0.92	17.82	4.04	0.98
facturing	2	19.95	37.56	2.62	20.76	37.51	2.62	20.08	37.49	2.62
	3	61.78	58.66	96.47	61.06	58.51	96.46	62.10	58.48	96.40

Table 3. Trade coefficients of selected commodities for 5 percent increase and 5 percent decrease in transportation cost in all regions.

Industry	Region	5 Percent Decrease Region 1	Region 2	Region 3	5 Percent Increase Region 1	Region 2	Region 3
Agriculture,	1	29.910	5.267	1.679	31.316	4.848	1.467
forestry, and	2	34.202	50.914	6.155	33.155	53.000	5.504
fisheries	3	35.887	43.820	92.167	35.529	42.152	93.029
Mining	1	16.838	1.311	0.937	18.064	1.188	0.854
	2	62.403	76.661	20.451	61.319	77.731	18.873
	3	10.760	12.028	68.612	10.617	11.081	70.272
Nondurable	1	25.789	4.210	0.770	26.954	3.823	0.670
manufac-	2	32.188	60.653	5.352	31.375	62.730	4.794
turing	3	42.023	35.137	93.878	41.666	33.447	94.536
Durable manu-	1	17.776	3.901	0.976	18.778	3.654	0.853
facturing	2	20.271	36.673	2.783	19.634	38.463	2.464
	3	61.953	59.425	96.241	61.589	57.884	96.683

the selected commodities before and after the deduction of a 5 percent decrease in transportation cost.

A 5 percent increase in transportation cost among all regions, which could be caused this year by the increase in Middle East crude petroleum prices, substantially increases the own trade coefficients in all three regions. For example, between the period before and after the 5 percent transportation cost increase, the own trade coefficient of durable manufacturing goods for region 1 jumps to 18.778 from 18.27 percent, to 38.463 from 37.56 percent in region 2, and to 96.683 from 96.47 percent in region 3.

Another interesting feature of this study is that the trade coefficient in all regions changes in response to a change in transportation cost between any two regions. The 5 percent decrease in transportation cost between region 1 and region 2 also changes the import structure of region 3. For example, after the reduction of transportation cost between regions 1 and 2, the region 3 importation of nondurable manufacturing goods from region 1 increases from 0.72 to 0.73 percent and its importation from region 2 increases from 5.06 to 5.07 percent. There is no change in transportation cost between regions 1 and 3 nor between regions 2 and 3, but their trade coefficients have changed.

The next item investigated is the effect on regional growth and deflation of the 5 percent decrease in transportation cost. Two cases are considered: Case 1 is a 5 percent decrease in transportation cost between regions 1 and 2, and case 2 is a 5 percent decrease in transportation cost among all three regions.

A 5 percent decrease in transportation cost between regions 1 and 2 stimulates region 1 the most. The nondurable manufacturing industry in region 1 grows as much as 2.99 percent, followed by agriculture at 2.94 percent, mining at 2.37 percent, and the durable manufacturing industry at 2.15 percent. The construction, financial, and service industries share the same growth rate: 0.79 percent. In region 1, the industries that exhibit the least growth effect are trade; government; and transportation, communication, and utilities. Their rates of growth are 0.30, 0.35, and 0.57 percent, respectively.

A relatively weaker impact is observed in region 2 in the above case. After the 5 percent reduction in transportation costs, agriculture, forestry, and fisheries grows only 0.53 percent, followed by durable manufacturing at 0.31 percent; mining at 0.29 percent; nondurable manufacturing at 0.28 percent; construction at 0.17 percent; finance, insurance, and real estate at 0.13 percent; and the service industry at 0.11 percent. Industrial growth rates in region 3 are virtually unaffected by the decrease in the cost of transportation between regions 1 and 2.

When a 5 percent decrease in transportation cost occurs among all three regions, the regional impact is much stronger than in the previous case. The agriculture, forestry, and fisheries industry in region 1 is stimulated as much as 9.78 percent in output growth—the largest growth rate among all industries. The output of the durable manufacturing industry increases 8.98 percent, followed by nondurable manufacturing at 7.53 percent, mining at 6.89 percent, construction at 2.58 percent, service at 1.90 percent, and transportation, communication, and utilities at 1.70 percent.

The 5 percent decrease in transportation cost among all regions also stimulates the industrial growth of region 2. The strongest growth rate again occurs in agriculture, forestry, and fisheries—5.50 percent—followed by durable manufacturing at 4.85 percent, mining at 3.40 percent, nondurable manufacturing at 3.25 percent, construction at 2.11 percent, and finance, insurance, and real estate at 1.08 percent.

Because the base-year industrial outputs in region 3

Table 4. Deflation and growth impact of 5 percent decrease in transportation costs.

		Regions 1 and 2 Only		All Regions	
Region	Industry	Output Change (%)	Price Decrease (%)	Output Change (%)	Price Decrease (%)
1	Agriculture	2.94	1.07	9.78	2.56
	Mining	2.37	0.48	6.89	0.98
	Construction	0.79	0.64	2.58	2.07
	Nondurable manufacturing	2.99	1.34	7.53	2.73
	Durable manufacturing	2.15	0.66	8.98	2.20
	Transportation, communications, and utilities	0.57	0.30	1.70	0.64
	Trade	0.30	0.19	0.93	0.44
	Finance	0.79	0.18	1.56	0.42
	Service	0.79	0.29	1.90	0.80
	Government	0.35	0.23	0.95	0.57
2	Agriculture	0.53	0.16	5.50	1.41
	Mining	0.29	0.05	3.40	0.37
	Construction	0.17	0.13	2.11	1.66
	Nondurable manufacturing	0.28	0.14	3.25	1.23
	Durable manufacturing	0.31	0.11	4.85	1.54
	Transportation, communications, and utilities	0.06	0.03	0.80	0.34
	Trade	0.04	0.03	0.36	0.24
	Finance	0.13	0.03	1.08	0.24
	Service	0.11	0.05	0.92	0.48
	Government	0.05	0.04	0.54	0.37
3	Agriculture	0.03	0.02	0.78	0.36
	Mining	-[a]	-[a]	0.55	0.16
	Construction	0.01	0.01	0.26	0.23
	Nondurable manufacturing	0.02	0.02	0.56	0.37
	Durable manufacturing	0.01	0.01	0.44	0.23
	Transportation, communications, and utilities	-[a]	-[a]	0.10	0.10
	Trade	-[a]	-[a]	0.02	0.04
	Finance	-[a]	-[a]	0.03	0.03
	Service	-[a]	-[a]	0.09	0.07
	Government	-[a]	-[a]	0.08	0.08

[a] Change smaller than 0.005.

are much larger than those of regions 1 and 2, the growth effect in region 3 is much smaller than that in either of the other regions. Region 3 covers the rest of the United States, excluding the west-south-central section. Because of the high base-year output, the percentage change in output—which is calculated by dividing the change in output by the base-year output—becomes relatively smaller. The growth rate in agriculture, forestry, and fisheries in region 3 is 0.78 percent, followed by nondurable manufacturing at 0.56 percent, mining at 0.55 percent, durable manufacturing at 0.44 percent, and construction at 0.26 percent. Trade, finance, service, and government are highly insensitive to the transportation cost change. Their growth rates are only 0.02, 0.03, 0.09, and 0.08 percent, respectively.

Transportation cost is a part of business cost, and lower transportation cost between regions 1 and 2 further lowers the price of nondurable manufacturing goods in region 1 by as much as 1.34 percent. Farm price is reduced by 1.07 percent, the price of durable manufacturing goods by 0.66 percent, and construction service price by 0.48 percent. The price impact in region 2 is observed mostly in the farming industry, where the price decreases by 0.16 percent, followed by nondurable manufacturing goods at 0.14 percent, construction at 0.13 percent, and durable manufacturing goods at 0.11 percent.

The price impact of the decrease in transportation cost is much stronger when the decrease occurs among all three regions. The biggest price decrease occurs in region 1 in nondurable manufacturing goods, the price of which goes down by as much as 2.73 percent. The prices of agricultural products, durable manufacturing goods, construction services, and mining products are down by 2.56, 2.20, 2.07, and 0.98 percent, respectively. The same industrial groups in region 2, except mining, show the largest price declines in regions 2 and 3 in response to the 5 percent decrease in transportation cost among all regions.

Agriculture, durable and nondurable manufacturing, construction, and mining are generally highly sensitive to both changes in output and price and a change in transportation costs. The growth and price responses of government; service; finance; trade; and transportation, communication, and utilities are less sensitive to transportation cost change.

Table 4 gives data on the deflation and growth impact of a change in transportation costs.

CONCLUSIONS

Regional technical coefficients and trade coefficients are endogenous variables to the MVIO model. These coefficients are the results of the optimizing behavior of the firms in each region. Transportation cost is one of the input costs that the firms wish to minimize. A change in transportation cost affects the regional technical coefficients and the trade coefficients because the firms' input mix from each region has to be changed.

A major limitation of the model is the assumption on the linear logarithm production frontier. The specification implies a unitary elasticity of substitution between a pair of inputs and a constant share of input. The input share as an approximation to the input elasticity may be another limitation of the model.

The model shows that the regional technical coefficients and the trade coefficients are sensitive to the change in transportation costs. In general, an increase in transportation costs forces firms to buy and sell more of their products in their local markets and to import less of their inputs from other regions. The own trade coefficients increase as transportation costs increase. The cross trade coefficients, which are the off-diagonal elements of the trade-coefficient matrix, decrease as transportation costs increase. The sensitivity of trade coefficients to the change in transportation costs differs among commodities. Manufactured goods are more vulnerable to the cost change than are agricultural goods.

Transportation costs affect regional development and inflation. Some industries are more susceptible to the change in transportation cost than others. In general, manufacturing, mining, and agriculture are more susceptible, whereas trade, government, and communications are less susceptible.

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Discussion

Hays B. Gamble

The main contribution of the paper by Liew and Liew appears to be one of adopting a methodological approach (interregional input-output) to the analysis of the effects of changes in transportation costs. They assume a 5 percent change in such costs, but the effects on trade coefficients are quite slight, well within the normal variations that exist, solely because of errors in data measurement. Moreover, they use 1963 data, which are too old to have much meaning. Their findings are therefore really quite meaningless, and any merit of the paper must rest on the methodological adaptation of interregional input-output. I think this point should be stressed.

Authors' Closure

The empirical results presented in our paper should be considered as an illustration of the working of the model. The data need to be updated for current policy evaluation, but the implications of the empirical results should provide interesting insight for transportation planners and the freight industries.

We are not sure precisely what "errors in data measurement" means. The effect on trade coefficients is simply a result of the simulation of the model. Elsewhere, we compiled the effect on trade coefficients under varying degrees of change in transportation cost, and the impacts are significant.

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Quantitative Technique for Estimating Economic Growth at Nonurban, Limited-Access Highway Interchanges

Richard D. Twark, Raymond W. Eyerly, and Richard B. Nassi

A quantitative modeling technique for estimating the economic development that is likely to occur at a given nonurban interchange site on the Interstate highway system is described. It was important that the model be easily implemented by using secondary data on economic, demographic, geographic, and other characteristics. A sample of 128 nonurban Pennsylvania interchanges was selected. Problems in the quantification of variables and restrictions imposed by the lack of data for certain variables were discussed. Simple, multiple, and stepwise linear regressions were useful in identifying promising variables for the modeling technique. The structural design of the model was formulated by using 15 exogenous variables that define the economic, demographic, geographic, and traffic environment and the following five endogenous variables: service stations, restaurant seats, motel rooms, industrial developments, and other commercial developments. The forecasting model consisted of a set of simultaneous linear equations. The simultaneous-equation model usually gives better estimates than single-equation models. A two-stage least-squares technique was used to estimate the parameters of the model. All equations of the model were statistically significant. The model can be a useful tool in helping planners to predict land use changes at existing or proposed nonurban interchange sites. When applying it to a specific interchange, the user is cautioned to observe the total environmental setting for peculiar or unique characteristics.

An important provision of the Federal-Aid Highway Act of 1956, which authorized the Interstate highway system, was the prohibition on roadside developments such as gasoline stations, restaurants, and motels with direct access to Interstate rights-of-way. Since traffic to and from a limited-access highway must be channeled through an interchange and highway users traveling long distances do not ordinarily want to go far from an interchange in search of gasoline, food, or lodging, an interchange is an advantageous location for the construction of establishments such as service stations, restaurants, and motels.

Just as many present trade centers, towns, and cities can trace their origins to the existence of transportation crossroads such as river junctions and railroad connections, which provided improved linkages between local land uses and distant land uses, the interchange area also offers an opportunity for community development by reason of improved access between land uses (1). The development of commercial or industrial establishments, recreational facilities, residential units, and the abovementioned highway-oriented establishments at an interchange stimulates general business activity, creates new jobs, increases income, and expands the tax base of the community.

The spontaneous economic development of an interchange community is a complex phenomenon. There is considerable variety in the economic sectors—residential, commercial, industrial, etc.—that form communities, and the growth pattern of one community will differ from that of another. For example, the speculative withholding of land from the market may delay the growth of the community, whereas the establishment of a new industrial plant close to a residential area may substantially promote community growth.

THE PROBLEM

An Interstate highway may create new market potentials and make possible a change in the mix of goods and services that a community can offer; this will affect the balance of the economic sectors of the community. Not all interchange areas have the same potential for economic development. This is supported by the fact that some have developed in a very short period of time while others have shown no development even after many years.

The volume of traffic entering and exiting various developments in an interchange area is of particular importance to transportation planners. Their concern centers on present and/or changing land uses that have high rates of trip generation. The capacity and safety of a highway system that may currently be adequate can be subjected to severe strain as adjacent land uses change. One of the key elements in solving the problem of the premature obsolescence of interchanges is the ability to forecast probable land use developments.

The basic purpose of planning and regulating development at an interchange area is not ordinarily to restrict but to encourage growth. If changes in land use at interchange areas are not adequately considered, they can result in social and economic losses to the highway user, the interchange community, and the state. To the motorist, the consequences of inadequate land use planning may result in delays, increased accident exposure, higher operating costs, visual blight, and excessive energy consumption. To the local communities and state authorities, these consequences are even more burdensome, causing expensive highway redesign, installation of corrective traffic controls, and the loss of employment opportunities and tax revenues because of marginal and/or inefficient land use. Finally, all consequences of inadequate planning contribute to degrading the environmental quality of interchange areas.

On the other hand, an adequate land use plan will encourage the most efficient use of land, coordinate mainline and cross-route levels of service with traffic generated by land uses, meet the public's need for access and services, stimulate the growth of employment opportunities and tax revenues, and maintain a desirable environmental appearance.

This investigation is primarily concerned with the development of an econometric model for predicting selected highway- and non-highway-oriented developments that are likely to occur at a given nonurban interchange site. A very practical consideration is that the model be designed so that it can be implemented easily by using secondary data.

PREVIOUS STUDIES

Several models have been formulated to forecast potential economic development at nonurban Interstate highway interchanges. Stein (2) reported that most states had initiated some form of interchange development study during the 1960s, often with the cooperation of the U.S. Department of Transportation (then the Bureau of Public Roads).

An extensive study in Michigan by Ashley and Berard (3) analyzed the development that occurred near 66 interchanges on a 290-km (180-mile) span of I-94. The investigation was conducted 3.5 years after the opening of the highway. A classification scheme attempted to provide a predictable pattern of benefits for other or future interchanges by comparing them with similar classes of interchanges on existing facilities (Ashley and Berard defined benefits as the enhancement or increase in value of adjoining lands as a result of the location and construction of a highway).

Fowler, Stocks, and Sanders (4, p. 16) developed a mathematical model that would make it possible to predict the extent of highway-service business growth at nonurban interchange areas. Their study used multiple linear regression in an analysis of 79 interchanges in eight states in the eastern United States. The model, which was composed of three equations, was designed to predict the amount of service station, restaurant, and motel development per interchange. A bias was introduced in the results by the elimination of interchanges that lacked service stations, restaurants, or motels.

Pendleton (5) examined aerial photographs and monitored land use before and after the construction of interchanges on toll and nontoll roads. He mentioned that the development of a forecasting model was beyond the scope of his work but laid a foundation for future interchange modeling work. Pendleton's work pointed toward two factors that should be included in any future mathematical forecasting programs: (a) the amount of development that existed before the construction of the interchange and (b) the distance between the interchange and an urban population center.

In a study of 105 nonurban interchanges in Pennsylvania, Twark (6) developed a simultaneous-equation model for predicting service stations, restaurants, motels, non-highway-oriented businesses, and average annual rate of growth in market value of real estate in the local interchange community. A two-stage least-squares procedure was used to estimate the parameters of the model. The resulting numerical coefficients (or parameter estimates) were based on nonurban interchanges that, on average, had been open to traffic for only 4.8 years.

In Alabama, Mason and Moore (7, p. 106) attempted to forecast aggregate levels of development by interchange design. Two models of interest were highway-oriented development at rural interchanges and service-station development at rural interchanges, which explained 26 and 29 percent, respectively, of the variance from the means. The researchers concluded that, because of limited sample sizes and data problems, it was not possible to develop a statistical statement that would have a high degree of reliability.

Epps and Stafford (8) statistically investigated the relation between the amount of interchange development and the characteristics of interchanges. The analysis consisted of using multiple regression techniques to relate the amount of development to a series of variables that represented traffic flow and demographic and locational characteristics. A regression equation was developed for each of the three highway-oriented types of businesses: service stations, restaurants, and motels.

Corsi (9), in a study of 15 Ohio Turnpike interchanges, designed linear multiple regression equations to forecast total land use, residential land use, highway-oriented and non-highway-oriented commercial land use, and industrial land use.

Researchers at the University of Texas at Austin (10, p. 58) reviewed many studies of rural interchanges and suggested that an ideal methodology for studying highway interchanges should include a long, continuous study period; encompass the interchange area of influence; and have independent variables that reflect physical, social, and economic factors necessary to characterize a community's development and potential for growth.

So far, these models have been based on the premise that future economic growth is a function of the economic, geographic, demographic, and traffic parameters of the specific site. The problem with most previous studies is that the models are inadequate for predicting future development, either because of the short range of time or because of aggregation of data for statistical purposes. The techniques used in the work described in this paper attempt to overcome some of the major deficiencies of previous studies.

GENERAL MODEL

The goal of this study is to develop a model that identifies the interrelationships among the important factors that lead to interchange development and to provide planners with a guide to the estimation of potential development in nonurban interchange areas. When they know the probable level of interchange area development, state and local planners can prepare a reasonable land use plan for the interchange that provides adequate highway service levels and fulfills other community needs.

There are problems involved in attempting to develop a means of predicting economic development in interchange areas. Some of the initial points to be established involve proper definition of (a) the interchange area, or "interchange community", and (b) the economic development or "economic growth" of an interchange community. Another problem is how to quantify the various factors that determine the differences in the economic growth of interchange communities.

The geographic area to be included, or the boundary of the interchange community, is not easily determined. Some authors have used the term "interchange area" rather loosely to cover the entire vicinity in which the existence of the interchange may stimulate intensive use of land that would not otherwise have been located there (11, p. 106). Others have used the term "area of influence" to mean the area in the vicinity of the interchange that is affected by the facility (12).

Various studies have found that, for nonurban interchanges, the majority of new economic development occurs within 0.8 km (0.5 mile) of the interchange (13, p. 72). Some arbitrary limitation of the area of the interchange community is necessary, and the boundary chosen will have some adverse effects on the applicability of the model to interchanges where exceptional geographic or topographic conditions lead to important developments farther away. This study considers the interchange community as the area located within 0.8 km of the interchange.

Since the economic growth of a community is such a complex process, any description of the state or level of development for a given community must involve the measurement of the many characteristics of that community. To predict the development of the community as a whole, each of the variables that measure a particular characteristic or sector of the community would have to be predicted. Because of the interrelationships of these variables, each one affects the growth of the community and is in turn affected by that growth. For example, as a residential community grows, a need develops for service facilities such as grocery stores, gasoline stations, and variety and drug stores, and this development encourages further residential expansion.

The economic growth of an interchange community is considered to be determined by two types of factors: (a) endogenous variables, which describe the state or levels of economic development for the given community, and (b) exogenous variables, which affect the level of economic development of the interchange community but are not generally affected by the growth that takes place.

It is assumed here that the entire model can be presented as a system of simultaneous linear equations in which each equation describes how a particular aspect of economic development (endogenous variable) is determined by other relevant endogenous and exogenous variables. Such an equation describes a particular "structure" of the economic community and is called a structural equation of the model. Any one of the structural equations in the model will have the same mathematical appearance as that of an ordinary multiple regression equation. However, the parameters of a structural equation in a system of equations generally cannot be derived by using ordinary regression techniques. Other suitable methods have been developed, one of which should be used.

The method of estimation used in this research is the two-stage least-squares technique (14, p. 376). The estimates of the parameters of the structural equations obtained by this technique are asymptotically unbiased.

By appropriate definitions, the system of structural equations can be represented by the following matrix form:

$$YA = XB + e \tag{1}$$

where

Y = endogenous variables,
X = exogenous variables,
A and B = respective parameters of the variables, and
e = aggregate effects of the unspecified variables.

The solution of this system of equations would be

$$Y = XBA^{-1} + eA^{-1} \tag{2}$$

which can be written

$$Y = XC + u \tag{3}$$

where $C = BA^{-1}$ and $u = eA^{-1}$. The above solution is the matrix representation of the "reduced" form of the structure.

The importance of the structural equations can be illustrated by their ability to estimate the marginal effect on different types of development at an interchange when the level of some other type of development has been determined to be different from that predicted by the reduced-form equation. For example, the reduced-form equations may estimate the economic potential of some particular interchange to be very small. However, if for any reason the site should be selected for a large motel, this would change the potential of the interchange, and the structural equations could be used to estimate the effect of the motel on further development of the interchange, such as the likely appearance of service stations and restaurants.

An enormous number of variables may influence the economic development of an interchange community. Many of these variables may have very slight effects, whereas others are not quantifiable. Still others may be unique for a given area. It is not practical to include all of these variables in a model. The model therefore specifies only the variables thought to be most important. The net effect of the excluded variables for each equation is then represented by the disturbance term e.

A review of related literature revealed that there is considerable variability among interchanges. This suggests that a relatively large number of observations should be required before generalizations are made with any degree of confidence.

PRELIMINARY ANALYSIS

A sample consisting of 128 nonurban Pennsylvania interchanges was selected. Data on economic, demographic, geographic, traffic, and other characteristics for each interchange were obtained from secondary sources and from direct observation, which involved visiting each interchange site.

Even though the important characteristics that describe an interchange community have been identified, there remains the problem of measurement. The goal of this research was to provide an easy-to-use method by which highway planners can predict future developments. The data must therefore be easily observable or available from secondary sources. The objective was to allow the measurement of the less refined variables that still provide a reasonable forecast of an entity. For example, investments such as service stations might be reflected better in annual dollars of retail sales or average number of employees, but such data were not readily available. To overcome the measure's inability to characterize the intensity of development, categories such as number of pumps, number of seats, and number of rooms were added to the initial measures of service stations, restaurants, and motels, respectively. In the same way, it would have been desirable to have demographic data for the interchange community in refining the research model, but such information does not exist in a basic form suitable for easy insertion into a forecasting model. It should be noted that variables that require extensive data collection may provide better results but could make the use of the modeling techniques costly for highway and planning agencies.

The data were analyzed by using descriptive statistics, simple correlations, and multiple regressions as aids in designing the general forecasting model. Service stations, the most frequent form of new development, average two stations per interchange, followed in order of frequency by other commercial developments (such as the businesses found in small community shopping centers), restaurants, motels, industrial developments, and, finally, public developments such as highway maintenance shops or state police barracks.

On the average, service stations, restaurants, and motels appeared to follow an approximate ratio of 4:2:1. The ratio of other commercial development to industrial development was approximately 3:1. Highway- and nonhighway-oriented developments had an approximate ratio of 3:2. Although ratios among development levels may be important in the aggregate, they are often not accurate for specific interchanges.

The basic data for the exogenous variables used in this study were the age of the interchange since its opening, the presence of zoning at the interchange area, the distance to the nearest urban area, average daily traffic (ADT) on the Interstate highway and cross route, and the population, area, and market value of real estate in the local community, the county, and the nearest urban area associated with the interchange. Combinations and ratios of some of the basic data were constructed to form 26 exogenous variables. For example, variables such as population and market value of real estate were placed on a common base, such as market value per capita and/or population per unit area. In addition, other variables were constructed to depict change over time. The exogenous variables were classified in four main categories: local community, county, nearest urban area, and ADT.

CORRELATION AND REGRESSION ANALYSIS

Correlation is often a useful aid in model building. As a further step in model construction, simple correlations were obtained between 26 potential exogenous variables and 13 potential endogenous variables. Few exogenous variables, with the exception of cross-route ADT, were consistently significant in the simple correlations across all endogenous variables. Significant correlations were obtained between the exogenous variables and industrial and other types of commercial development in all four main exogenous classifications, especially for the local community and ADT variables.

The representation of economic functions must incorporate the multiple facets of the real world. Since it was recognized that a myriad of economic, demographic, geographic, and highway parameters and their interrelationships influence the development of interchange areas, a multiple regression analysis was undertaken.

In view of the many pitfalls and possible data interactions involved in attempting to identify significant variables for the model, the prime consideration in adding, deleting, or modifying a variable was that a logical (though sometimes subjective) basis must be established for such changes. In some instances, because of various interactions, variables that appear significant in simple correlation analysis may not be significant when combined with other variables in a multiple regression analysis; in other instances, the reverse may be true.

Multiple linear regressions in which 1975 levels of development (13 potential endogenous variables) were used were run against all of the 26 potential exogenous variables. The low proportion of explained variation (R^2) obtained for truck garages and public developments—0.161 and 0.155, respectively—suggested that a model for forecasting these developments on the basis of the exogenous variables contained in this study would not be very accurate. These two variables were therefore dropped from further consideration as potential endogenous variables for the final model.

An extensive series of stepwise multiple linear regressions was useful in the identification of promising variables for the model. Many multiple regressions were examined and edited to add and subtract variables, which led to an increase in the proportion of explained variance. The extensive series of stepwise analyses indicated that selected equations were equally capable of predicting service stations and number of gas pumps. Service stations were selected as being more appropriate for the final model because they can be translated into traffic generation units for planning purposes more easily than the number of gas pumps. On the other hand,

Table 1. Endogenous and exogenous variables included in simultaneous-equation model.

Type of Variable	Symbol	Description	Time Frame	Actual Data Year
Endogenous	Y_1	Service stations	t_{+5}	1975
	Y_2	Restaurant seats	t_{+5}	1975
	Y_3	Motel rooms	t_{+5}	1975
	Y_4	Industrial developments	t_{+5}	1975
	Y_5	Other commercial developments	t_{+5}	1975
Exogenous	X_1	Community population density	t_0	1970
	X_2	Change in community population density	t_{-10}- t_0	1960-1970
	X_3	Community real estate market value per square kilometer	t_0	1970
	X_4	Change in community real estate market value per square kilometer	t_{-10}- t_0	1960-1970
	X_5	Community real estate market value per capita	t_0	1970
	X_6	Change in community real estate market value per capita	t_{-10}- t_0	1960-1970
	X_7	Age of interchange since opening	t_{+5}	1975
	X_8	Cross-route ADT	t_0	1970
	X_9	Total ADT, cross-route plus Interstate	t_0	1970
	X_{10}	County population density	t_0	1970
	X_{11}	Change in county population density	t_{-10}- t_0	1960-1970
	X_{12}	County real estate market value per square kilometer	t_0	1970
	X_{13}	County real estate market value per capita	t_0	1970
	X_{14}	Change in county real estate market value per capita	t_{-10} - t_0	1960-1970
	X_{15}	Nearest urban area population to distance ratio	t_0	1970

the equations were substantially better able to predict restaurant seats and motel rooms than number of restaurants and number of motels.

SIMULTANEOUS-EQUATION MODEL

A major attribute of the simultaneous-equation model is that it usually gives better estimates than single-equation models. As indicated previously, developing the particular structure of a general model that can reasonably be expected to describe and predict economic development at interchange sites is a complex task. The relevant variables must be identified and classified into endogenous and exogenous categories.

Statistical theory alone does not provide firm guidelines for the inclusion or exclusion of a particular variable in any given equation of the simultaneous-equation model. According to Wonnacott (15, p. 300), "Prior belief plays a key role, not only in the initial specification of which variable should be in the equation, but also in the decision as to which should be dropped in light of the statistical evidence."

The results of the preliminary analysis suggested that the endogenous and exogenous variables given in Table 1 be included in a simultaneous-equation model. Table 1 also identifies the time frame for each variable. Assuming the present time to be t_0, the planning year forecasted is t_{+5}, and the exogenous variables are based on their levels at t_0 or changes in the variables from t_{-10} to t_0.

Next, the structural equations must be constructed, and the parameters of the equations then have to be estimated. There are as many structural equations as endogenous variables, since each equation explains the level of a particular measure of development in terms of the levels of all other variables. Equation design followed the general criterion of using a limited number of easily measured and time-lagged variables. The format of the final set of equations, which is given below, was designed to forecast service stations, restaurant seats, motel rooms, industrial developments, and other commercial developments:

Equation	Item Forecast	Variables Included: Endogenous	Exogenous
1	Service stations	Y_2, Y_5	X_2, X_8, X_9, X_{11}, X_{12}, X_{14}
2	Restaurant seats	Y_3	X_5, X_8, X_9, X_{11}, X_{12}, X_{13}, X_{14}
3	Motel rooms	Y_2	X_2, X_3, X_4, X_8, X_9, X_{10}, X_{11}
4	Industrial developments	Y_2, Y_5	X_2, X_3, X_5, X_7, X_9, X_{10}, X_{11}, X_{13}, X_{15}
5	Other commercial developments	Y_1, Y_4	X_1, X_2, X_4, X_6, X_7, X_{10}, X_{15}

The statistical method of estimation chosen for this study is the two-stage least-squares technique, which comprises a system of reduced-form equations and a corresponding series of structural equations.

A reduced-form equation is an ordinary multiple regression equation that expresses an endogenous variable (Y_i) as a function of the entire set of exogenous variables (X_i's). Since there are five endogenous variables, there will be five reduced-form equations. The first reduced-form equation for service stations would appear as follows:

$$Y_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 = \ldots + \beta_{15} X_{15} \quad (4)$$

The equations for restaurant seats, motel rooms, industrial developments, and other commercial developments would be similar in nature. The system of reduced-form equations can be viewed as providing a rough estimate of the economic potential at an interchange.

The importance of the structural equations is in their ability to estimate the marginal effect on different types of development at an interchange. The reduced-form equation may show the economic potential of an interchange at one level. If a restaurant were built at the site, the economic potential for the interchange might have increased, since the structural equation might suggest the likely appearance of service station or motel development. For example, the structural equation for service stations would be as follows:

$$Y_1 = f(Y_2, Y_5, X_2, X_8, X_9, X_{11}, X_{12}, X_{14}) \quad (5)$$

where the function f is assumed to be linear and

Y_1 = number of service stations,

Y_2 = number of restaurant seats,
Y_5 = number of other commercial developments,
X_2 = change in community population density,
X_8 = cross-route ADT,
X_9 = total ADT (cross-route plus Interstate),
X_{11} = change in county population density,
X_{12} = county real estate market value per square kilometer, and
X_{14} = change in county real estate market value per capita.

In addition to providing a description of the marginal effects of the relevant endogenous variables (Y_2, Y_5) and exogenous variables (X_2, X_8, X_9, X_{11}, X_{12}, X_{14}) on service-station development Y_1, the structural equation can be used for forecasting purposes.

Note, however, that unlike the reduced-form equation for service stations, which contains only exogenous variables as predictors, the structural equation contains two endogenous variables (Y_2 = restaurant seats and Y_5 = other commercial developments). Values for these variables can be "preset" to simulate differing conditions, or they can be estimated by using the reduced-form equations. These estimated values ($\hat{Y}_2$, $\hat{Y}_5$) would permit the structural equation to forecast service stations Y_1. The equation would appear as follows:

$$Y_1 = f(\hat{Y}_2, \hat{Y}_5, X_2, X_8, X_9, X_{11}, X_{12}, X_{14}) \quad (6)$$

Similarly, the remaining four equations can be identified by referring to the preceding text table and then to Table 1 for the description of variables.

RESULTS AND RELIABILITY OF THE MODEL

The model is designed to use information that would be available and inexpensive to obtain. The model forecasts on a 5-year time horizon (t_{+5}) by using data from a model base year (t_0) and from 10 years before the base year (t_{-10}). In this study, the model base year was 1970. Hence, t_0 = 1970, t_{-10} = 1960, and t_{+5} = 1975. Data necessary for t_{-10} and t_0 can usually be obtained from secondary data sources, whereas t_{+5} requires only a determination of years elapsed since the opening of the interchange to traffic.

Estimates of the parameters (i.e., regression coefficients or β-values) for the reduced-form equations are given in Table 2. Estimates of the parameters for each of the five structural equations, along with levels of statistical significance, are given in Table 3. The levels of significance for the two-stage least-squares method are only approximate because the estimated parameters

Table 2. Regression coefficients for reduced-form equations of the model.

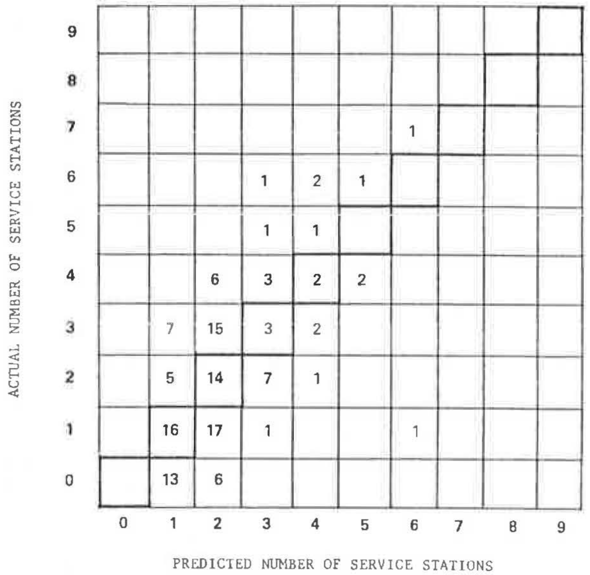
Variable Symbol	Service Stations	Restaurant Seats	Motel Rooms	Industrial Developments	Other Commercial Developments
X_1	0.000 422 82	0.075 927 33	0.056 178 56	-0.000 992 84	0.003 967 48
X_2	-0.010 280 53	-0.997 604 56	-0.270 139 77	0.004 882 91	0.025 292 85
X_3	-0.000 001 18	-0.000 149 70	-0.000 058 74	0.000 001 02	-0.000 000 22
X_4	0.000 002 18	0.000 274 92	0.000 107 86	-0.000 001 18	-0.000 003 27
X_5	-0.000 057 05	0.026 105 43	0.002 678 48	0.000 013 43	-0.000 373 50
X_6	-0.000 017 83	-0.011 052 28	0.000 075 90	0.000 009 86	0.000 679 03
X_7	-0.042 111 40	-6.892 275 00	-0.417 441 43	0.037 839 47	0.092 237 64
X_8	0.000 277 33	0.032 658 78	0.014 450 38	-0.000 030 43	0.000 089 24
X_9	0.000 007 41	-0.000 410 62	-0.001 792 69	0.000 047 94	0.000 068 93
X_{10}	-0.010 774 29	-2.053 554 78	-0.454 444 64	-0.001 601 66	-0.017 508 35
X_{11}	-0.021 350 43	-3.402 202 53	-0.865 929 38	-0.000 794 56	-0.020 186 76
X_{12}	0.000 003 55	0.000 623 27	0.000 138 61	0.000 000 75	0.000 005 10
X_{13}	-0.001 139 06	-0.194 786 76	-0.043 188 11	-0.000 427 32	-0.001 374 53
X_{14}	0.001 275 09	0.196 495 65	0.055 376 36	0.000 361 40	0.001 716 75
X_{15}	0.000 003 45	0.001 991 82	0.000 766 93	-0.000 021 09	0.000 029 90
Constant term	4.419 570 22	512.566 808 64	97.497 337 29	-0.005 572 36	1.971 363 26

Table 3. Structural equations.

Variable Number	Service Stations (R^2 = 0.364)		Restaurant Seats (R^2 = 0.812)		Motel Rooms (R^2 = 0.789)		Industrial Developments (R^2 = 0.334)		Other Commercial Developments (R^2 = 0.319)	
	C	S[a]	C	S[a]	C	S[a]	C	S[a]	C	S[a]
$\hat{Y}_1$									0.642 596 76	0.03
$\hat{Y}_2$	0.002 745 50	0.02			0.191 492 34	0.0000	-0.000 307 30	0.41		
$\hat{Y}_3$			3.297 726 34	0.0000						
$\hat{Y}_4$									0.180 183 44	0.42
$\hat{Y}_5$	0.120 005 52	0.22					0.094 439 38	0.23		
X_1									0.004 639 79	0.01
X_2	-0.004 565 31	0.03			-0.167 996 79	0.13	0.001 669 30	0.17	0.032 158 79	0.001
X_3					-0.000 018 27	0.09	0.000 000 31	0.015		
X_4					0.000 063 74	0.05			-0.000 004 35	0.004
X_5			0.010 004 22	0.01			0.000 027 47	0.25		
X_6									0.000 250 60	0.02
X_7							0.038 955 90	0.09	0.127 598 55	0.04
X_8	0.000 162 97	0.01	-0.015 703 54	0.05	0.007 527 08	0.0002				
X_9	-0.000 015 57	0.33	0.003 468 90	0.11	-0.001 145 39	0.10	0.000 036 19	0.08	0.000 047 77	0.23
X_{10}					-0.015 858 51	0.28	0.000 816 85	0.14	-0.002 491 35	0.07
X_{11}	-0.003 984 43	0.32	-0.209 708 69	0.39	0.001 156 63	0.498	-0.000 040 46	0.497		
X_{12}	-0.000 000 07	0.40	-0.000 012 84	0.33						
X_{13}			-0.018 156 12	0.30			-0.000 164 66	0.04		
X_{14}	-0.000 194 16	0.11	-0.019 601 02	0.36						
X_{15}							-0.000 023 50	0.02	0.000 036 06	0.11
Constant	1.619 946 49	0.0001	85.753 694 26	0.07	2.960 407 55	0.40	-0.500 386 49	0.13	-2.487 985 89	0.06

Note: C = regression coefficient; S = probability significance level.
[a]Uses a one-sided t-ratio and indicates the likelihood that the relation could have been a chance occurrence.

Figure 1. Comparison matrix of actual versus predicted numbers of service stations per interchange.



of the structural equations and their standard errors are not unbiased. Since, however, the technique does generate asymptotically unbiased estimates for the parameters, the relatively large sample size (n = 128) should provide a "rough" guide to significance levels.

Each equation was tested and found to be statistically significant by using the classical F-test at the 1 percent level or less. The proportion of explained variation ranged from approximately 32 percent for other commercial development to 81 percent for restaurant seats. A Student's t-test at the 10 percent level resulted in other commercial developments having the greatest number of significant variables (7) and service stations and restaurant seats having the least (3). The equations for motel rooms and industrial development each had five significant variables.

Cross-route ADT, as expected, was highly significant in explaining highway-oriented development—i.e., service stations, restaurant seats, and motel rooms. It was the most important factor in explaining service-station development and ranked second and third, respectively, in motel-room and restaurant-seat development.

The equation designed to forecast restaurant seating is one of the more capable developed in this study. The variable that provided the strongest relation with restaurant seats was number of motel rooms. This close association can be explained, in part, by the fact that many motel developments integrate restaurants as part of their services. This close association also held true in the structural equation designed to forecast motel rooms.

The most important factors that explained other commercial development were local community factors. Change in community population density was the most significant. This suggests a strong reliance of other commercial development (as defined in this study) on the local community in which the interchange is located.

To visualize the model's ability to forecast development, matrices were constructed to compare actual and forecasted levels. If the model predicted perfectly, all values would lie along the diagonal of a matrix. An example of the matrix for service stations is shown in Figure 1. The cell counts represent the number of interchanges. The model forecasted accurately within the target ranges approximately 27 percent of the time for service stations, 46 percent for restaurant seats, 48 percent for motel rooms, 59 percent for industrial development, and 34 percent for other commercial development. The capability of the model to predict the level of development within two categorization units is higher than 90 percent for each endogenous variable.

CONCLUSIONS

The research reported in this paper has developed a method to forecast potential growth levels at highway interchanges. The model can be used in the planning and design of future interchanges and land use regulation. It is applicable to the study and simulation of the impacts of various interchange sites before the final location and design of a specific interchange. It can also be used in the redesign of obsolete interchanges.

In this study, a five-year planning horizon was used to develop a model that was essentially static in nature. Many of the interchanges in this study experienced an initial increase in service stations, motels, or restaurants but little change in subsequent years. On the other hand, non-highway-oriented developments tended to develop slowly and continued to grow as the interchange matured. Research into dynamic modeling would be desirable where the levels of the variables change over time and the sequences of the endogenous variables are described. Designing and determining the proper structure for such a dynamic model are complex tasks that could be aided by the results of this study.

The predictive capabilities of the model might be improved by using more refined measures of development than the "crude" measures used in this effort. A criterion of this study was to use easily discernible variables. However, attributing a value of one to an industrial development indicates its existence but gives no indication of the size or scope of the business, the space requirement, or the traffic generation potential.

One factor that might show promise as a measure is gross floor area of commercial and industrial development. Traffic generation rates for restaurants, shopping centers, and offices are expressed in units of gross floor area, which makes the model's results directly applicable (16, p. 135).

In addition, the total number of parking stalls or area for public and employee parking might provide a better rough measure of endogenous development than this study's method of "binary" measurement of one if a development exists or zero if otherwise, without regard to the extensiveness of the enterprise. Generally, it follows that the larger the development is, the greater is the number of employees and, on the average, the greater is the parking area. This may not hold true for a highly automated manufacturing plant or a development served by public transit.

Finally, the move to suburban and nonurban areas is still in progress in many American cities. Nonurban interchanges close to cities may become targets for rapid, possibly unrestrained, new development. The model may be applicable in the initial stages of urbanization. As the area urbanizes further, new equations would have to be constructed by using the methodology developed for the present model.

The user of the model should keep in mind that the parameter estimates for the model were based on historical data. Structural changes in the general economy, such as the cost and availability of energy or governmental policies, might significantly alter the values of the variables on which this model is based. To the extent that these changes occur, the model forecasts may tend to be inaccurate. Thus, an update of the parameter estimates should be undertaken.

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Abridgment

Transportation Regulations in an Urban Economy: A Dynamic Model of Their Impacts

William H. Crowell and Arnold J. Bloch

An effort to assess the various economic impacts of vehicle restrictions and transit incentives in an urban setting by using a dynamic, interactive simulation model is discussed. The Manhattan central business district (CBD) serves as a focus for the modeling effort. The transportation actions studied are strategies proposed for the local transportation control plan, as required for New York City and most urban areas under the Clean Air Act of 1970. Changes to the CBD business sector (volume of business and employment), the transportation sector (vehicle volumes and mode splits), and the residential sector are studied. The model, which uses the Dynamo structure, is dependent on key simplifying assumptions joined in a feedback relationship in such a way that the effects on one sector influence changes in another. The model finds that the traffic-reduction strategies accomplish their goals only at the expense of economic well-being and that transit inducements alone have the snowballing effect of increasing business and vehicle activity in the CBD. However, combining vehicle-restraint policies with transit inducements can relieve congestion, primarily through modal shifts rather than reduced customer activity, so that the economic consequences are less onerous.

This paper discusses the effort to assess, through use of a dynamic, interactive simulation model, the various economic impacts of selected transportation policies and programs (1). The types of transportation actions examined are those developed as part of an urban area's transportation control plans (TCPs). Under the Clean Air Act of 1970, states that include urban areas in which motor vehicle emissions are a significant part of total emissions must develop a TCP that outlines how these "mobile source" emissions are to be reduced. New York State submitted such a plan for New York City in April 1973. It included fairly strong proposals and strategies for reducing vehicle traffic, focused mainly on motor vehicles traveling to, from, or within the Manhattan central business district (CBD)—the area from the southern tip of Manhattan to 59th Street. However, a number of these strategies, particularly those that included parking reductions, new bridge tolls, and trucking constraints, were met with strong public resistance in New York City. The principal source of these negative responses was the Manhattan business community, which felt that such traffic constraints would increase the difficulties and costs of shopping and doing business in Manhattan. As a result, these most-controversial strategies were eventually deleted from consideration as part of any air quality plans. [The political pressures against the bridge-toll plan were so strong that a provision was included in the Clean Air Act Ammendments of 1977 forbidding the U.S. Environmental Protection Agency (EPA) from enforcing such plans if alternative air quality strategies could be offered.]

But the legal requirement to provide a workable means of reducing vehicle emissions still remained. These policy problems were joined with more recent concerns to achieve energy conservation and transportation system management (TSM) goals (i.e., to expand highway and transit capacity through low-cost methods). These additional public mandates have kept such strategies, originally developed under the aegis of air quality requirements, very much alive in the minds of transportation planners (2, 3). Because of extensive resistance to many transportation schemes, it became imperative that any new TCP options, as well as those developed for other social goals, be reviewed to assess the full range of primary and secondary impacts (4). Chief among these are the economic effects, especially those on the Manhattan CBD, where more than 1.6 million persons work at 80 000 businesses and where thousands more reside and shop.

For these reasons, the Polytechnic Institute of New York was contracted to assess the nature and extent of the economic impacts of TCPs on the Manhattan CBD. In addition to a major survey of more than 400 firms in Manhattan (5, 6), a transportation-economic activity model was developed, of aggregate dimension, to help define functional relations among economic sectors as well as simulate the types of impacts that would result from various general transportation actions. The model was intended as a "first-cut" planning tool, to demonstrate patterns and order-of-magnitude economic adjustments in the CBD that result from specific transportation actions. Clearly, the model structure could not directly reflect the full complexity of the Manhattan CBD. Such relations must be simplified by the extensive use of assumptions. As long as these assumptions are reasonable, this aggregating process in no way invalidates the merits of the study. Indeed, the value of such an analytic tool is that it can test the range of results of the implementation of various plans in a dynamic system that analyzes multiple strategies simultaneously over different time frames. This frequently exposes the flaws of plans that are drawn up in a limited, isolated context, which often ignore such real-world interrelationships.

CBD DYNAMIC MODEL

The model developed for this study uses the Dynamo program and language originally developed by Forrester of the Massachusetts Institute of Technology (MIT). These models have been used to study the dynamics of such complex systems as urban areas and business (7) as well as the relationship among world population, food sources, and natural resources (8). Such models are characterized by their (a) explicit exposition of assumptions and (b) use of "flows" and equations. Essentially, these Forrester-type dynamic models are composed of three elements:

1. Levels, or the state or condition of the system at any particular time;
2. Rates, or actions that cause the levels to change; and
3. Feedback situations, whereby levels and rates are joined in a continuous loop, affecting one another.

The feedback loop is the basic structural element in systems. Complex systems, such as the CBD model developed for this study, are composed of many single and interlocking feedback loops. The model processes all the loops through a step-by-step computation of relevant equations. Together, they produce a simulation solution.

The model describes conditions only in the CBD, although it is necessarily dependent on the movement of commuters, customers, and potential CBD residents from areas external to the CBD. The conditions with which the model is concerned are the following:

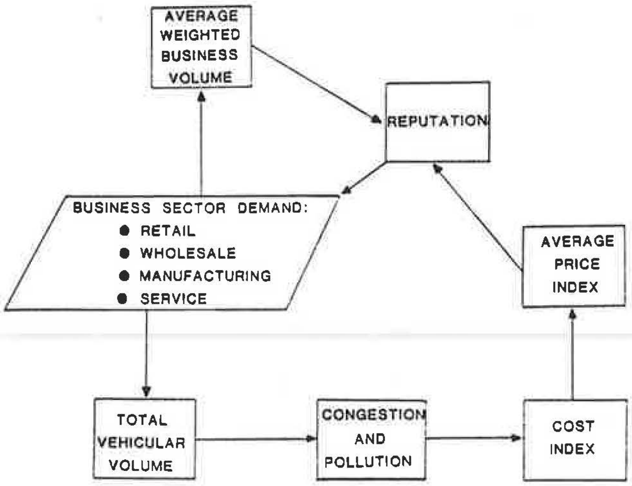
1. Economic—the level and climate of economic activity in the CBD, including employment and the demand for goods and services within industrial sectors;
2. Residential—the attractiveness of the CBD to present and potential residents; and
3. Transportation—the transportation picture in the CBD, including total and single-mode traffic volumes, transit use, and the mode splits of employees, residents, and customers.

In the model, the attractiveness of CBD business, residential opportunities, and travel modes is affected by such TCP-type actions as (a) a 150 percent increase in tolls on river crossings entering the CBD, (b) a 50 percent increase in the cost of CBD parking, (c) a 50 percent increase in the cost of taxi fares, and (d) a 50 percent decrease in mass transit fares. The model deals only with the impact of these traffic-restraint and transit-inducement strategies. Other factors, such as taxes, crime rates, the quality and cost of housing, and the quality of education, which are clearly related to the level of economic activity in the CBD, are held constant.

The major economic policy variables in the model are the levels of business activity in the retail, wholesale, manufacturing, and service sectors along with total CBD employment and residential population. The interrelationship among these factors is the most complex aspect of the model and needs some specific exposition.

Potential demand for goods and services in each of the four sectors is a function of many variables. "Reputation", so named to reflect the changing capability of the CBD to function as a business center, appears as a multiplicative variable in each sector equation. It is computed as the ratio of prior business activity to the average level of business prices. As Figure 1 shows, average price index is a direct function of the cost index, which is a weighted sum of costs derived from congestion and pollution (as well as from TCP policy actions). Thus, reputation has self-enforcing qualities; it enhances business growth to the point where added traffic or policy action generates costs too great for the system

Figure 1. Segment of the Dynamo model.



to bear, causing a depressing impact on economic activity.

Other variables that affect business-sector demand include (a) employment and residential levels (each consumes retail- and service-sector products), (b) the demand for goods or services in each of the other sectors (e.g., retail activity spurs demand in wholesale, manufacturing, and service sectors), and (c) demand by external customers (non-CBD workers or nonresidents).

The demand generated for goods and services in each business sector is combined into an average weighted CBD business volume. This variable becomes the numerator in the next computation of the reputation ratio but also directly affects the level of CBD employment. Employment level in turn affects (a) residential activity, (b) retail- and service-sector demand, and (c) total CBD vehicle volume.

Mode choice for employees, residents, and business-related travel is affected by (a) the implementation of TCP actions and (b) improving or worsening conditions of congestion and pollution in the CBD. The level of congestion and pollution is assumed to be a simple additive function of the number of automobiles, taxis, and trucks in the CBD. Total traffic volume is, in turn, affected by (a) the total number of CBD travelers (a function of activity in the four business sectors plus total employment and resident population) and (b) the mode split of these travelers.

STRATEGIES

Each of the selected strategies implemented in the model produced output in two principal areas: (a) economic activity levels and (b) transportation activity and mode-split data. The model normalizes all variables to an initial value of 100 (except for mode-split fractions) and therefore expresses all impacts as changes in these indices (i.e., the equivalent of percentage changes). All of the results presented below are those that result at the end of 50 months, the average time for the perturbations in all of the variables to subside. To reiterate, the individual TCP strategies tested in this model are the following:

1. Increased tolls—A 150 percent increase in tolls is used to simulate the tolling of all currently free river crossings into the Manhattan CBD (13 river crossings are currently free, whereas 6 have a round-trip fare of $1.50). This directly enters mode-choice decisions and the costs of doing business and eventually works through all of the model's (i.e., the economy's) sectors.
2. Increased parking cost—The 50 percent increase in the costs of parking in the CBD is used to simulate the impact of a surcharge on existing rates.
3. Increased taxi cost—The 50 percent rise in taxi costs represents either an actual rate hike or the change in taxi customers' perceived total cost of choosing that mode because of a midtown cruising ban that makes taxis less accessible.
4. Reduced transit fare—The 50 percent drop in the transit fare represents an average reduction in fares in all time periods and on all transit modes entering and traveling within the CBD.

Table 1 gives the effect that each of these strategies, taken separately, had on a variety of economic indicators of business activity in the Manhattan CBD (all variables had an initial value of 100); the data given in Table 2 show how these plans changed the overall volume of traffic (and related congestion and air pollution) and the changes in the use of individual modes. The toll strategy has a relatively strong impact when it is compared with the other three plans, in terms of business volume, employment, and total traffic volume. The taxi plan has very little impact on anything but taxi use (which switches to private cars and public transit), whereas parking has somewhat more extensive repercussions although considerably less than the tolling scheme.

The transit example, however, demonstrates the type of interesting and often unexpected results that the model points out. Although automobile users were switching to transit, total traffic increased more than 7 percent because of the greater use of trucks and taxis, especially trucks. The increases in business activity caused by lower transit costs require more transportation support services for the higher volumes of goods and person movement. This result points out the need for counterbalancing strategies that respond to the dynamic nature of transportation-business interactions and is further highlighted by the multistrategy results discussed below.

IMPACT OF SELECTED STRATEGY COMBINATIONS

Each combination of the four strategies, including the four-strategy option and all two- and three-strategy groupings, was tested for its impact on the same range of economic and traffic variables. The following strategy combinations will be discussed:

Plan	Strategy Combination
1	Toll increase and parking surcharge
2	Toll increase and transit-fare decrease
3	Taxi-fare increase and transit-fare decrease
4	Toll increase, parking surcharge, and transit-fare decrease
5	Toll increase, parking surcharge, transit-fare decrease, and taxi-fare increase

Tables 1 and 2 give the impact of these combinations; Figure 2 compares the effect on business volume of the combined toll and transit-fare strategies versus the effect of each strategy taken separately. The results shown simulate the economic consequences that are possible under an overly restrictive transportation plan. Increased tolls and parking costs, for example, do produce a desired drop in traffic volumes, but they also cause a significant reduction in economic activity and employment, eventually hurting the manufacturing and service sectors the most. In contrast, when the same two strategies are combined with a transit-fare reduction, the economic consequences are much less severe, overall traffic volume is still lowered, and transit rider-

Table 1. Effect of individual strategies and strategy combinations on various economic levels.

			Business Sector				External Customers[b]		
Strategy	Total Job	Average Volume of Business[a]	Retail	Wholesale	Manufacturing	Service	Retail and Service	Wholesale and Manufacturing	CBD Residents
Individual									
150 percent toll increase	92	91	93	91	89	90	94	96	99
50 percent parking surcharge	98	96	97	97	95	95	102	99	100
50 percent taxi-fare surcharge	99	99	99	99	98	99	102	102	101
50 percent transit-fare reduction	112	113	111	110	116	116	99	105	101
Combined									
Tolls and parking	88	88	89	89	86	86	92	97	98
Tolls and transit	99	99	101	97	98	99	99	95	102
Taxi and transit	109	110	109	108	112	112	107	99	101
Tolls, parking, and transit	97	95	97	94	93	95	97	96	102
All four strategies	96	94	97	94	92	94	99	98	103

Note: Base = 100.
[a]Weighted measure (by sector employment) of the activity ongoing in the four sectors, averaged over a six-month period.
[b]External customers travel into the CBD to conduct business with any of the four sectors.

Table 2. Effect of individual strategies and strategy combinations on transportation sector levels.

	Vehicle Volume				
Strategy	Total[a]	Automobiles	Trucks	Taxis	Transit Ridership
Individual					
150 percent toll increase	91	89	90	95	94
50 percent parking surcharge	96	89	96	101	98
50 percent taxi-fare surcharge	97	108	99	86	103
50 percent transit-fare reduction	107	95	113	105	117
Combined					
Tolls and parking	88	79	87	95	92
Tolls and transit	94	83	98	95	107
Taxi and transit	101	101	110	87	118
Tolls, parking, and transit	90	73	94	96	105
All four strategies	87	79	94	82	108

Note: Base = 100.
[a]Also used in the model as a direct measure of pollution and congestion.

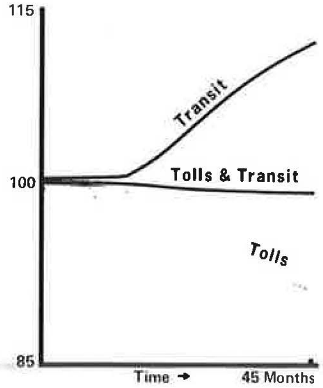
ship increases. However, it must be remembered that, even if the overall impact is relatively small in aggregate economic terms, significant economic adjustments may be necessary and some firms will be losers. The plan that has the most favorable impact on traffic congestion and pollution is the combination of all four strategies, which cuts automobile and taxi use by 21 and 18 percent, respectively, while increasing transit patronage by 8 percent. Analyses of mode-split data showed that most of this shift from automobile to transit occurs among journey-to-work travelers and retail and service customers and clients. In addition, the size of the CBD residential sector, which plays an important role in the model, increases by almost 3 percent.

Wholesale and manufacturing modal decisions are, as expected, usually the least affected by any of the five plans. In contrast, external retail and service customers—the group frequently mentioned as the most vulnerable to travel restrictions—are understandably sensitive to plan 1 (toll and parking surcharge). Their volume, however, is only slightly affected (and even increased) by all of the other plans, even when the overall demand for the retail and service sectors decreases.

The data in Table 2 also show a seemingly contradictory consequence—cheaper transit increasing traffic congestion, which is caused by the additional vehicular support required by the increasing CBD business induced by the improved transit access. The impact of this increase in commercial and industrial activity is shown in the virtually unchanged level of employment under a toll increase and a transit-fare decrease versus an 8 percent drop with tolls alone. The additional mode-shift incentive provided by low-cost transit also has the expected impact on the mode choice of automobile versus transit; CBD automobile traffic drops more than 17 percent under plan 2 versus 11 percent with tolls alone.

The results shown above do, however, highlight one very clear concept (and challenge) for transportation planners involved in TCP design and implementation: The price of cleaner air may often be reduced economic activity. Congestion and pollution are by-products of economic activity, and changing the "pollution intensity" of activities in the short term through pricing and regulatory controls can cause adjustment losses. Plan 2 causes a 5-6 percent drop in traffic at very little cost to the economy; the all-four-strategies option, by comparison, provides a 12-13 percent decrease in traffic volumes but at a higher economic cost. It is clearly

Figure 2. Effect on business volume of combined toll and transit-fare strategies versus separate implementation of each strategy.



important to combine strategies carefully to balance off traffic restrictions with alternative incentives while realizing that it may take time for a less polluting economic base to replace that portion lost because of air quality policies.

CONCLUSIONS AND RECOMMENDATIONS

The principal result of the modeling efforts reported in this paper is the policy trade-off between traffic reduction and reduced economic activity. The assumptions, estimates, and data embodied in the model's interrelated sections show, when applied together in the dynamic framework of the Dynamo-based model, that (a) many traffic reduction schemes can seriously damage the CBD economy and (b) the only economically viable method of reducing traffic volumes is to counteract the effects of vehicle-restraint policies (e.g., higher tolls) with transit inducements. The key is to try to relieve traffic congestion through mode-split changes rather than changes in the levels or patterns of business or customer activity.

The effectiveness of any plans reviewed here would obviously have to be compared with that of others currently under consideration by New York or any state for inclusion in a revised TCP as mandated by the Clean Air Act of 1977. If an inspection-maintenance program were implemented, for example, average emission factors (i.e., amounts of emissions per vehicle kilometers of travel) and associated total vehicle-related pollution would be reduced, possibly at a lower (public and private) social cost than, say, a modest parking-surcharge plan. The possible effects of other actions exogenous to air quality, such as dramatic increases in gasoline costs, clearly deserve analytic attention as well. Every effort should be made to coordinate parallel analytic efforts associated with TSM activities or other transportation areas to avoid duplication and to coordinate results and eventual decision-making processes.

In addition to the range of recommendations made here, the following efforts associated with the model itself deserve additional attention:

1. The model should be tested further, especially in relation to the interrelationships between the various business sectors and the validity of the key elasticity-of-demand values found to be so crucial to the overall results.
2. The potential to interface the model with other transportation analysis models, such as the Urban Transportation Planning System, should be examined, including the ability of the economic results to provide some feedback into such models in determining route alternatives, policy options, and the like. Possible coordination with relevant land use models should also be explored.
3. Factors necessary to the transferability of the model to other CBD areas or less dense urban and suburban areas should be examined, including those elements that need changing versus recalibration, the applicability to smaller-scale policies and actions (e.g., a 10-block bus-only mall), and the effect of adding other policy elements (e.g., an energy-reduction feedback loop to match the pollution and congestion mechanism in the present model structure).

Further work is also required in nonmodeling areas of economic impact analysis, especially in relation to projects that are highly localized—such as a small pedestrian mall or computer signalization of a portion of one major arterial—and projects that occur in areas that have relatively simple economic bases.

In summary, although there are many areas that deserve a more extensive research effort than was possible in this study, the model as it now stands was able to generate the type of necessary, first-cut decision-making assistance required by transportation officials. Although this cannot replace a more detailed analysis of the problems involved, it does offer a highly flexible tool for testing such alternatives in a rigorous yet understandable and relatively low-cost manner.

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Automobile-Restrictive Measures in Central Business Districts: Some Recent Findings and Views

Carla Heaton and Joseph Goodman

Increasing concern about the need to enhance the quality and economic vitality of urban areas, especially the downtown, has fostered interest in a broad set of transportation strategies that involve the restriction of automobile traffic. The Service and Methods Demonstration Program of the Urban Mass Transportation Administration has been examining two concepts of this type: automobile-restricted zones and transit malls. Background information is presented on various traffic-restriction projects that have been sponsored and/or evaluated under the program, and selected findings regarding the planning and implementation process, operations, and impacts of the projects are discussed. Experience with these concepts has been generally positive and encouraging. They have proved to be feasible to implement, workable in terms of traffic circulation and other operational aspects, and beneficial to transit users and pedestrians and have been well received by the public. They also appear to be compatible with broader public and private efforts aimed at revitalizing the downtown.

The Service and Methods Demonstration (SMD) Program sponsors the development, demonstration, and evaluation of innovative transit operating techniques and services that use existing technology. Many innovative methods of improving the quality and efficiency of urban transportation have been developed both by the Urban Mass Transportation Administration (UMTA) and by local areas and transit properties here and abroad over the past few years. The SMD Program focuses on deploying and evaluating these techniques in real-world operational environments and promoting the most promising of them to local transit operators, planners, and elected officials across the country.

This paper describes current SMD Program activities and preliminary findings regarding two innovative concepts—automobile-restricted zones and transit malls—whose central focus is the physical restraint of automobile traffic and the encouragement of transit use and pedestrian activities in the downtown. These concepts represent the first broad-based attempt in this country to redefine the role of the automobile in the downtown by placing physical restrictions on its use. Automobile-restricted zones and transit malls are appealing concepts for several reasons: (a) They rely for the most part on proven transportation systems management (TSM) strategies such as traffic engineering changes, preferential treatment for transit vehicles, and parking management techniques; (b) they are relatively low in cost and quick to implement compared with capital-intensive transportation improvements; (c) they encompass many aesthetic elements and amenities and can be designed to capitalize on the unique characteristics and functions of the downtown; and (d) they represent a visible commitment on the part of the public sector to promoting urban revitalization, energy conservation, and environmental quality objectives.

There are, however, some risks and uncertainties associated with automobile-restraint measures, and it is for this reason that the SMD Program has taken an active role in sponsoring demonstrations and studies of these concepts. One risk, perhaps most keenly perceived by elected officials, is the potential for public opposition. Closing off streets to traffic is a bold measure that directly challenges the freedom of individuals to operate their private vehicles when and where they please. There is a distinct possibility that one or more groups will attempt to obstruct either the planning or the implementation of such schemes. Another important question is whether changes of this nature and scale are operationally feasible. Particular concerns include excessive congestion on streets that receive the diverted traffic, potential problems with goods delivery and automobile access to parking facilities, and interruptions to commercial activities during construction.

The most significant uncertainty is the effect of automobile-restrictive measures on the economic viability of the downtown. From the perspective of the local business community, broad-scale restrictions of vehicle movement and parking may appear threatening because of their potential to discourage shoppers, workers, and, ultimately, business establishments. These concerns about adverse economic impacts are valid and may partly reflect the mixed U.S. experience with the small-scale pedestrian malls that were built in small and medium-sized cities during the 1960s and early 1970s. These malls were often designed to emulate and compete with the burgeoning suburban shopping malls. The results were spotty: The vitality of some central business districts (CBDs) was improved, but in other instances—for example, in the case of a declining CBD with an activity base insufficient to sustain large pedestrian volumes—the mall was unable by itself to countervail the forces of decline and blight.

Broad forms of automobile restriction are quite common, and have been quite successful, throughout Europe and the Far East. Planners and local officials in this country, however, have expressed some skepticism about whether such approaches are workable in American cities in view of their distinct physical, demographic, and institutional characteristics.

Partly in response to these uncertainties about the feasibility and suitability of automobile-restrictive measures in American cities and partly out of an interest in achieving substantial transit operational improvements in the downtown, the SMD Program embarked on a major research, development, and demonstration effort to assess the potential applicability, public acceptance, and impacts of these concepts. In 1975, a comprehensive study (1) was initiated to evaluate the feasibility of the concept of the automobile-restricted zone (ARZ), identify potential sites for demonstration projects, and develop detailed demonstration designs for several prospective sites. The ensuing site-screening and negotiation process culminated in four SMD projects that are now in various stages of implementation.

While the ARZ feasibility study was under way, the SMD Program initiated a study of transit malls that were being planned and implemented as a result of local initiative, independent of the demonstration program. The transit-mall study was done in two phases: (a) a site report that described the characteristics and histories of six transit malls in various phases of implementation

(2) and then (b) an in-depth impact analysis of three of the six projects (3).

This paper describes the transit-mall and ARZ projects that have been sponsored and/or evaluated by the SMD Program and presents summary findings from the transit-mall study. Finally, critical elements related to planning, implementing, and operating automobile-restrictive measures are discussed.

DESCRIPTION OF PROJECTS

The transit-mall and ARZ concepts embody a carrot-and-stick approach to innovation. Projects that entail physical or operational restrictions on automobile use also include a complementary package of incentives or improvements—for example, transit service improvements and pedestrian amenities—that are intended to maintain access into and within the restricted area, minimize adverse impacts on peripheral areas, and provide a more pleasant environment for people using the area.

A transit mall is a street (usually in the downtown) on which transit vehicles are given exclusive or near-exclusive access, sidewalks are widened, and amenities are added for pedestrians and waiting transit patrons. Automobile access is denied or strictly limited, except for cross-street traffic. A transit mall represents a compromise between preferential treatment for transit vehicles (e.g., priority lanes and signalization) and a full pedestrian mall.

Since the mid-1970s, transit malls have increased in popularity in the United States as a means of improving the operating efficiency and attractiveness of public transit while at the same time providing an improved environment for pedestrians and shoppers. Five transit malls have been completed, and several more are in various phases of planning, design, or construction. These projects have been implemented at local initiative by using a combination of local funds (from the city, transit district, or property assessments) and UMTA or Federal Highway Administration (FHWA) capital assistance funds. Table 1 summarizes the characteristics of three transit malls that were the subject of the in-depth SMD-sponsored evaluation.

An ARZ is an area created in a congested portion of a city, such as the central business or shopping district, where automobile traffic is prohibited or restricted. The focal point of the ARZ is a pedestrian enhancement zone. Other possible elements include linear transit malls that extend or connect the core to other pedestrian activity centers, new or rerouted transit service, reserved bus lanes, transit and taxi facilities, peripheral parking garages, special loading docks, and ring roads for the rerouting of through traffic. An ARZ generally requires a comprehensive redesign of the CBD street system and complementary traffic engineering changes to provide improved access for pedestrians and transit travelers while maintaining adequate internal and peripheral circulation for commercial, emergency, and through vehicles.

Table 2 summarizes the characteristics of the four ARZ demonstration projects. Figure 1 shows the major pedestrian, transit, and traffic changes in each project. As the following brief descriptions illustrate, the four projects offer considerable variation in terms of area characteristics, project scale, degree of restriction on vehicle traffic, and relative emphasis on transit versus pedestrian improvements. Project elements have been combined and designed to capitalize on the existing physical, transportation, and land use characteristics

Table 1. Characteristics of three transit malls.

Characteristic	Nicollet Mall, Minneapolis	Chestnut Street Transitway, Philadelphia	Fifth and Sixth Avenue Mall, Portland, Oregon
Project status	Completed in 1967, extension to be completed in 1979	Completed in 1976	Completed in 1978
Project cost ($)			
Total	3.8 million	7 million	15 million
Per square meter	161	236	355
Funding sources	74 percent assessment district, 13 percent UMTA demonstration grant, 13 percent Urban Beautification grant	80 percent UMTA capital grant, 16.7 percent state DOT, 3.3 percent city capital funds	80 percent UMTA capital grant, 20 percent Tri-Met, plus utility costs by departments and utility companies
Primary project backers	Downtown business	City government, planners, downtown business	City government, planners, downtown business
Area land use	Retail core, offices	Retail core, offices	Office core, intersects retail core
Expected benefits	Improved retail environment and bus service and operations	Improved retail environment, upgraded transit for Bicentennial crowds	Increased transit use and operational efficiency, improved retail-pedestrian environment, reduced suburban sprawl
Transit use	Standard transit buses, shuttle minibuses, rerouting onto mall	Standard transit buses, tourist buses, minor rerouting	Standard transit buses, rerouting onto mall
Nontransit use	Taxis, emergency vehicles, bicycles	Taxis at night, one block only during day; emergency vehicles; general traffic for parking lots (one block only)	General traffic on one lane for three out of four blocks
Peak-hour bus volume (number each way)			
Before	20	43	32 on Sixth Avenue, 95 on Fifth Avenue
After	60	41 eastbound, 11 westbound	175 on Sixth Avenue, 158 on Fifth Avenue
Pedestrian volume (pedestrians/block/h)			
Before	1068 (12-h period)		444 on Sixth Avenue, 686 on Fifth Avenue (off-peak periods)
After	1114 (12-h period)	3016 (peak periods on major blocks)	
Traffic signal treatment	Reset for cross traffic flow (computerized traffic control system scheduled)	Bus-triggered midblock warning light, signal timings set for expected bus speed, timings on nearby street reset	Computer-controlled with progression adjusted for traffic
Movement of goods	Alley loading, mall loading by special permit	Full-block street loading, loading on mall by special permit in off-peak hours	Cross-street loading, loading on mall by special permit in off-peak hours
Amenities	Extensive, including electric snow-melting mats, sign ordinance, heated bus shelters	Typical, with midblock crossing area	Extensive, including bus shelters and concession booths; CRT information display

Table 2. Characteristics of four ARZ demonstration projects.

Characteristic	Memphis	Boston	New York City	Providence
Project area	CBD and medical center (2 km apart)	Core retail district (1.8 km^2)	Times Square and theater district (0.07 km^2)	Financial and retail districts, Union Station
Transit availability	CBD served by 53 bus routes	CBD served by extensive rapid transit, bus, commuter rail systems	Area served by extensive subway and bus systems	CBD served by 32 bus routes
Transit mode split, all trips	19 percent, CBD	40 percent, CBD; 62 percent, project area	91 percent work, 75 percent nonwork, all project area	16 percent, CBD
Peak pedestrian volume	850/h on Mid-America Mall	5000-9000/h on major streets in area	5700-7300/h on major avenues	6500-7000/h on Westminster Mall
Primary project objectives	Improve transit link between Mid-America Mall and medical center, promote downtown revitalization	Increase retail sales, increase bus and taxi ridership, improve pedestrian environment	Promote economic development of area, improve transit service, enhance environment and identity of Times Square area	Connect downtown districts, enhance pedestrian environment, improve transit service, promote downtown revitalization
Project cost ($)	1.2 million	4.5 million	8.2 million	5.9 million
Funding source (%)	UMTA (S.3), 78; state, 8; local, 14	UMTA (S.3), 18; UMTA (S.6), 33; FAUS[a], 22; local, 27	UMTA (S.3), 33; UMTA (S.6), 6; FAUS[a], 18; state and local, 43	UMTA (S.3), 67; UMTA (S.6), 16; local, 17
Vehicle restrictions and/or circulation changes	No major changes (preexisting pedestrian mall)	Automobile traffic eliminated from 10 blocks, circulation pattern simplified	Automobile traffic eliminated from 4 blocks of Broadway, except cross streets; 7th Avenue widened	Automobile traffic eliminated from approximately 6 blocks
Parking changes (on-street spaces eliminated)	89	600 (400 illegal)	120	242
Goods movement	No major changes	New loading areas; deliveries before 11:00 a.m. on some streets, after 2:00 p.m. for some goods	Deliveries before 11:00 a.m.	New loading areas, loading restrictions, rerouting of goods vehicles
Transit modifications	Shuttle-bus service to medical center, downtown bus terminal, bus shelters	Bus-route extensions into area, exclusive bus lanes, bus waiting areas, five new taxi stands	One-block transitway, bus priority signalization, special taxi transit loading areas	Through bus routing, fare-free zone, new transit terminal and waiting areas, busways
Pedestrian changes	Sidewalk improvements	Full pedestrianization of several streets, sidewalk widening and improvements	Pedestrian plazas and sidewalk improvements	Exclusive pedestrian areas, sidewalk improvements
Project status	Terminal construction fall 1978 to spring 1979, sidewalk construction to begin spring 1980	Construction begun summer 1978, completed September 1979	Construction to begin spring 1980	Construction to begin fall 1980

Note: 1 km = 0.62 mile; 1 km^2 = 0.386 $mile^2$.
[a] Federal-Aid Urban System program.

of the areas and to be compatible with broader development efforts.

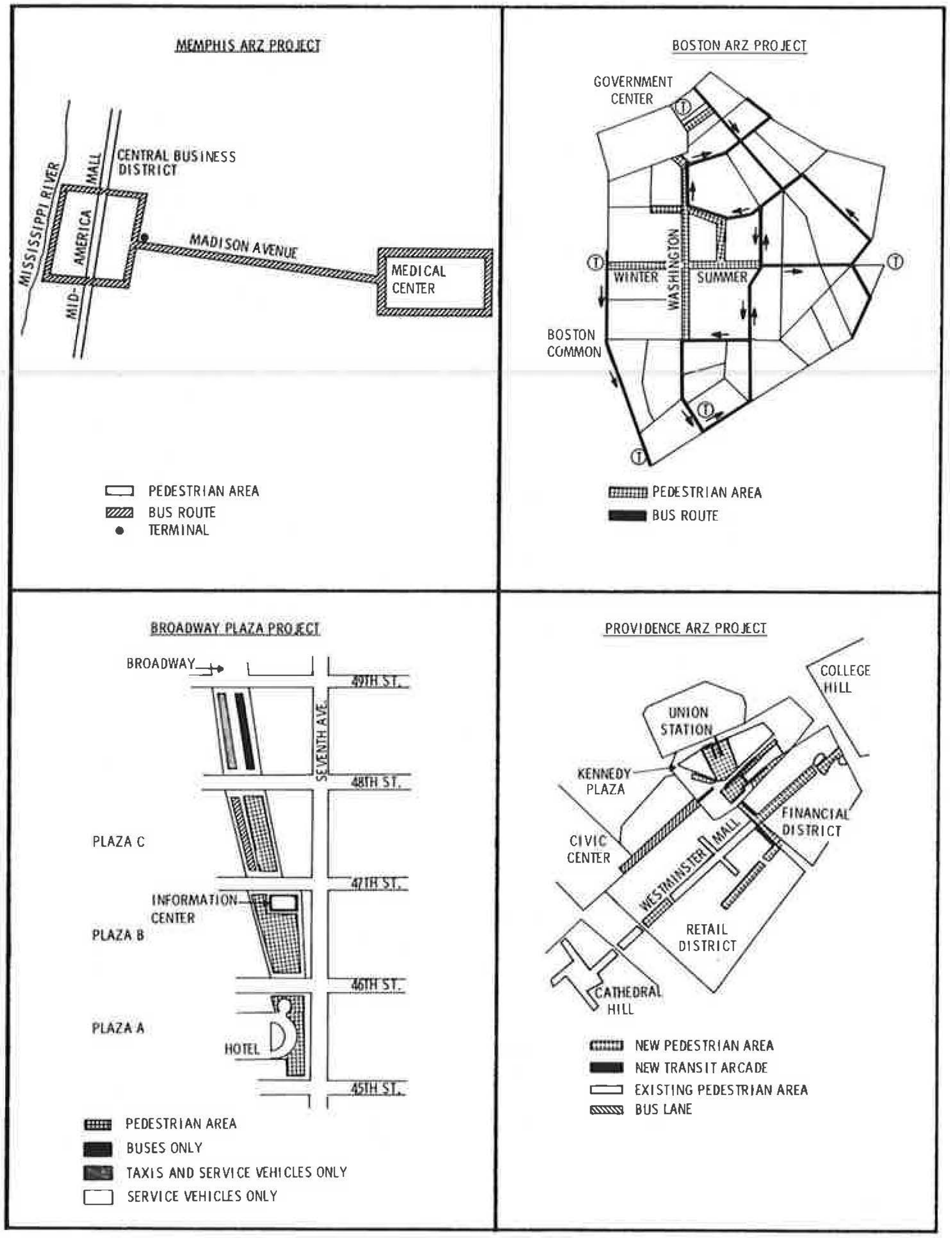
The Memphis ARZ, the simplest of the four plans, involves enhancement and extension of the Mid-America Mall, an eight-block pedestrian mall completed in 1976 at a cost of $7 million. The project is intended to provide a strong connecting transit link, by shuttle bus service, with a major employer located outside the CBD. Also included is the development of a downtown transit terminal, sidewalk improvements, and bus and pedestrian shelters.

The Boston ARZ is intended to link several retail, employment, and pedestrian activity centers in the heart of Boston. The project includes elimination of automobile traffic from 10 blocks in the core retail area, full pedestrianization of four major streets that have very high pedestrian volumes, the rerouting of express and local bus routes to provide direct access into the ARZ, and a variety of complementary elements such as street improvements, signing, relocation of taxi stands, and new loading areas.

Broadway Plaza in New York City is planned to include a linear automobile-free area from 45th to 48th Streets in the heart of the theater district and a transit mall from 48th to 49th Streets. Southbound traffic on Broadway will be rerouted to parallel facilities, and 7th Avenue will be widened to handle some of the diverted traffic. Vehicles will still be allowed to use cross streets. Other planned elements of the project include a motorist-guidance system, expanded loading areas for buses and taxis, and construction of a complete transit, theater, and tourist information center. The Broadway Plaza project is part of the comprehensive Times Square Action Plan, which involves zoning and tax incentives, stepped-up enforcement procedures, and specific private development projects such as a major new hotel complex abutting the southern end of the plaza. This hotel is estimated to cost $250 million, and its guest accommodations, convention facilities, and theater will be major generators of new trips. Although the hotel is not officially tied to the project, there has been extensive interaction between the hotel developers and the project staff to ensure that the design of this new attractor is compatible with expected pedestrian activities and flows on the plaza.

The ARZ project in Providence, Rhode Island, covers only a small portion of the CBD area but will provide an important pedestrian and transit link between the major CBD activity centers: the retail district, which already has a pedestrian mall; the financial district; and the refurbished Union Station. Limited right-of-way space is to be reallocated to pedestrians and transit, and major through circulation for automobiles is to be moved to the periphery. The plan calls for a main transit terminal, two busways, through routing of buses to minimize transfers, and a fare-free transit zone. The $5.9 million Providence ARZ project is to be implemented in the midst of a major downtown revitalization effort that involves $75 million of new public and private investment and, as in the case of Broadway Plaza, is being coordinated closely with these other planned developments.

Figure 1. Schematic maps of four ARZ demonstration projects.



FINDINGS ON TRANSIT MALLS

The in-depth evaluation of the Minneapolis, Philadelphia, and Portland projects examined three broad areas: (a) local conditions that affect the decision to build a transit mall and its subsequent design; (b) the cost of constructing, operating, and maintaining the mall; and (c) impacts of the mall on transit service, other vehicles, pedestrians, the economy, and the environment. In the case of the Portland mall, which opened in March 1978, there was an opportunity to collect before-and-after data. At the other two sites, which opened in 1967 and 1976, respectively, the analysis had to rely on comparisons between the transit malls and nearby unimproved streets. Salient findings regarding costs and impacts are presented below.

Transit malls are relatively inexpensive improvements compared with other capital expenditures for development or redevelopment. Construction costs range from \$161 to \$355/m^2 (\$15-\$33/ft^2). Major construction expenses include utility relocation, advanced-technology items, lighting, and pavement reconstruction; many project amenities are relatively inexpensive. Maintenance expenses for electricity, sidewalk repair, and cleaning run about \$60 000/block, which, because of a higher level of upkeep and more elaborate amenities, is higher than the rate for unimproved streets.

The reliability of bus service has improved, but transit travel times have remained approximately the same. In Minneapolis and Philadelphia, the absence of savings in travel time in comparison with unimproved streets is attributed to longer loading times and delays caused by traffic signal timing. Portland reports a trip-time reduction of about 50 percent (which may reflect unusually bad congestion before the mall), and new signal timing appears to allow smoother bus travel in Portland than in the other two cities.

Traffic diversion has not caused congestion on alternate streets. General traffic has been easily diverted by prominent mall entrances, informational and directional signing, and physical barriers. There have been relatively few violations of bus-only blocks by automobiles. Although automobile traffic entering the downtown areas has not decreased in any of the three cities, only minor increases in traffic have occurred near the transit malls. Motorists have either found parking at outlying locations or eliminated unnecessary circulation. Existing parking facilities have absorbed the lost on-street spaces at all three sites.

The problem of maintaining access for goods-delivery vehicles has proved tractable. Goods delivery has been least interrupted in Minneapolis, where rear alleys are used. Block-long cross-street loading zones in Philadelphia have been moderately effective, but delivery charges have increased for about 10 percent of the merchants. In Portland, where block lengths are shorter, cross-street loading appears to work well. Off-peak loading on the mall by special permit, as in Philadelphia, has not been helpful to small businesses that are unable to arrange precise delivery schedules.

Transit malls have created an attractive and convenient environment for pedestrians and transit users. Although there is no firm evidence that pedestrian volumes have increased, pedestrian amenities are well-used and pedestrian circulation has been improved by ramps, midblock crossings, and bus shelters. The pedestrian accident rate has not been affected, but bus-pedestrian conflicts other than accidents are higher than on unimproved streets. Factors leading to conflicts include increased jaywalking and the conversion of a one-way street to a two-way bus direction, as in Philadelphia. There is no evidence of bus speeding, and there is no widespread sentiment among pedestrians to remove buses from the malls.

Mall construction reduced pedestrian and business activity in Philadelphia and Portland, but the impact was less than that expected by merchants. Minimizing utility work in Philadelphia shortened the construction period, and careful phasing and the use of special walkways, especially in Portland, reduced interference to businesses.

There is no evidence of an overall increase in retail sales, at least in Philadelphia or Minneapolis, although the trend of declining retail sales may have been curtailed. Nonetheless, secondary economic indicators are positive: There are reports of national chain stores oriented toward young, middle-class customers moving in, low vacancy rates, increasing rental rates, and a rise in public and private investment. Transit malls and other downtown developments are mutually supportive; transit malls provide a retail focus and a transportation and aesthetic link between new developments. In Portland, the mall is felt to have acted as a catalyst for other redevelopment projects by demonstrating a firm commitment by the public sector to improving the downtown area.

IMPLEMENTATION OF CBD AUTOMOBILE-RESTRICTIVE MEASURES

The SMD-sponsored evaluations of the four ARZ demonstrations address a broad set of transportation, urban development, and institutional issues and impacts and are intended to produce transferable findings of relevance to policy formulation, planning, and implementation efforts at all levels of government. Since these demonstrations include explicit funding for data collection, there is an opportunity for more comprehensive and carefully designed measurement of changes in transportation level of service, travel behavior and activity patterns, environmental quality, land use characteristics, and economic conditions than was possible in the transit-mall study.

Given the current status of the four ARZ demonstrations and the fact that many of the changes being examined will take several years to materialize, it is still premature to comment definitely on the impacts of ARZs. However, preimplementation and early operational experience in Boston is quite encouraging: the project has been well received by the general public and by merchants, the street closings and changes in traffic circulation that occurred in September 1978 have not led to peripheral congestion, and operational aspects of the project such as construction and goods delivery have proved workable. [More detailed information on the evaluation and preliminary impacts of the Boston project is given elsewhere (4, 5).]

Perhaps the most important finding that has resulted from the projects is the need to involve potentially affected groups—various government organizations, transportation providers, business establishments, and the public—as early as possible in the planning and design process. This is especially important in the case of merchants who are concerned about the impacts of the project on retail sales and goods delivery. In Boston, downtown retailers had obstructed earlier proposals for pedestrian malls in the area and were somewhat skeptical at first about the ARZ proposal. They became enthusiastic supporters of the project partly in reaction to the success of the nearby Faneuil Hall development, which opened in 1976, and partly because of encouraging discussions with retailers from Philadelphia's Chestnut Street Mall. The views of merchant associations were solicited throughout the planning period on such matters as construction scheduling, design of street improvements, and strategies to maintain access for handicapped patrons and delivery vehicles.

Another finding is the need for a strong lead agency that has both the funds and the leverage to effectively coordinate and expedite the planning and implementation process. This is particularly true when funding for the project is being assembled from various public and private sources, each of which may have different administrative requirements and procedures.

In these projects, as in other types of projects that involve major changes in automobile and/or transit services, it is critical to launch an effective public information program well in advance of project implementation. The program should include multimedia promotion efforts and information leaflets for merchants, truckers, taxi operators, and other affected parties. In addition, there must be a comprehensive and comprehensible signing system to indicate how vehicles should proceed around or into the area and when various restrictions are in effect.

The early operational experience in Boston suggests that effective enforcement of traffic, parking, and loading restrictions is critical. Although it has been achieved at a cost considerably greater than that originally anticipated, the combination of a visible police presence at boundary points and an active ticketing and towing program has served the dual function of promoting public awareness of the project and ensuring adequate capacity for diverted traffic on peripheral streets.

Proper phasing of construction activities and proper sequencing of changes in traffic circulation and transit service are also very important. In Boston, merchants were adamant that construction activities not interfere with the 1978 Christmas shopping season. When delays in the start of the project made it impossible to complete construction by October of that year, activities had to be suspended for a few months to appease the merchants. Another phasing issue in Boston that would certainly be relevant to other cities was the need to dovetail project-related improvements with street and utility maintenance work.

The final factor that has been critical to smooth implementation in Boston has been the flexibility and responsive attitude of the project staff. Not surprisingly, there were many complaints and some confusion during the first few weeks regarding delivery restrictions, signing, allocation of maintenance responsibilities, and bus-routing changes. Staff members, however, were able to continue a precedent established during the planning phase—i.e., meeting with the affected group(s) to resolve problems in a mutually satisfactory manner. In many instances, the outcome was a modification to the project design and operational procedures, such as reopening a street to traffic and restoring a bus route. This responsiveness to operational difficulties forestalled the build-up of severe opposition to the project and is viewed as a critical factor in its acceptance by the general public.

Favorable evidence regarding the economic impacts of CBD automobile-restrictive measures is currently based on only a few cases, and more definitive conclusions must await analysis of before-and-after data from the ARZ projects. But it is clear from examination of the first generation of transit-mall and ARZ projects that there is tremendous potential for coordinating these projects with broader urban revitalization efforts. It is hoped that these bold and imaginative approaches toward managing the roles of the private automobile, transit, and pedestrians in the downtown can serve as useful bases and stimulation for broader-scale policy formulation and planning related to the management of automobile use.

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Abridgment

The Politics of Impact: The Case of Road Pricing

Tom Higgins

Suggestions for conducting the study of largely untried and controversial transportation concepts, such as road pricing and other automobile-restraint measures, are presented. The suggestions derive from the observation that the impacts studied and projected by planners may be unimportant or unbelievable or may not be borne out in the eyes of actors and interest groups important to the course of the study. Recent road-pricing studies conducted by the Urban Mass Transportation Administration and the Urban Institute are cited as an illustration. It is concluded that the impact perceptions of public policymakers and interest groups should not be discounted but should help to define the impact analysis. Furthermore, these perceptions should lead the way to (a) contingency planning for worst cases or (b) changes in the transportation concept being studied and tested.

The concept of road pricing represents an instructive case in which impact analysis confronts adverse public and decision-maker perceptions. Let us begin the case with the analyst's point of view, then turn to the view of policymakers, and finally draw some lessons.

PERCEPTIONS OF ANALYSTS

For analysts attracted to the efficiency and effectiveness of road pricing, the Singapore area license plan is an admirable example that has been well documented and evaluated by the World Bank (1). Singapore is not unlike many urban areas. It is a relatively dense and active metropolis that has almost 150 000 registered private vehicles and 1.5 million people living within 8 km of the central area. In 1975, the city government instituted a license requirement for vehicles (except commercial vehicles, buses, carpools of four or more, and motorcycles) entering a core-area zone of about 3x4 km between 7:30 and 10:15 a.m. The license takes the form of a window sticker priced at S$80/month and S$4/day (in 1975, US$1 = S$2.3713). A monitoring force stationed at 22 entry points notes violators and writes citations that are then mailed to vehicle owners. In addition to the license requirements, park and ride (10 000 spaces around the zone) and a 100 percent increase in parking charges at public lots within the zone were instituted. The zone was designed to allow through traffic to use a ring road, which was resignaled to accommodate increased flows.

All of these measures had immediate and lasting impacts on the city's traffic. The number of cars entering the zone between 7:30 and 10:15 a.m. fell by 73 percent, from 42 790 in March to 11 363 in September and October 1975. The volume before 7:30 a.m. rose by 23 percent, and carpooling increased by about 60 percent during the restricted hours. Allowing for the flows of vehicles other than cars, the net result has been a 44 percent reduction in total traffic during the restricted period. Evening peak flows have changed very little. Speeds within the zone increased 22 percent over the evening peak, although speeds on the ring road decreased by 20 percent in the morning compared with the evening peak. For people who worked within the zone and drove by car, the proportion of car trips fell from 56 to 46 percent; the bus share rose from 33 to 46 percent, and carpooling increased from 14 to 41 percent.

It is not hard to find the attraction for analysts in Singapore. It rests on the effectiveness and efficiency of road pricing. Compared with many strategies in the set of transportation system management (TSM) options, road pricing in the form of area licenses is a very effective and efficient way to reduce traffic densities when and where they create problems of congestion, excessive noise, neighborhood intrusion, or pollution, for the following reasons:

1. A supplementary license scheme such as Singapore's can be easily adjusted by time, location, and degree. Tailored bus lanes, staggered work hours, carpooling programs, or gasoline taxes to fit the temporal and zonal character of traffic densities are more difficult to implement than changing the time of day or the boundary within which stickers are required.
2. Experience with many of the low-capital-intensive options suggests that they may not be as effective in reducing traffic as the Singapore road-pricing scheme. U.S. experience to date does not show the significant (44 percent) and lasting reduction in vehicle traffic that resulted in Singapore from the roadway and parking pricing scheme combined with transit expansion.
3. While fuel and parking taxes generate revenues, as does road pricing, these taxes are harder to adjust to traffic densities. Fuel taxes affect all trips, and parking taxes miss through trips that may significantly contribute to traffic densities.

The relatively small or short-lived impacts of many low-capital-intensive schemes are briefly described below.

Busways

At best, busways appear to have had small effects on traffic or to have held traffic growth constant for a few years. Such appears to be the result in the case of the Golden Gate Bridge (3 percent traffic reduction) (2), the Seattle Blue Streak (traffic reductions attributable to a local recession) (3), the Shirley Busway (minor impacts) (4), and the San Bernardino Busway (no effects identified) (2). There is also some evidence that traffic reductions may be short lived. In Los Angeles, cars that used surface streets appeared to move onto the freeway as the busway created new capacity (5). There are not many examples of busways on surface streets, and no significant effects have resulted from the examples that do exist (6).

Variable Working Hours

It is only in cities that have a high proportion of government agencies or large firms that variable working hours might reduce traffic density. In the Ottawa program, where almost 50 percent of central-area workers were included in the program because of the dominance of the Canadian government as an employer, the rates of peak-hour to peak-period traffic (7:00-9:30 a.m. and 3:00-6:00 p.m.) fell by 5-10 percent, depending on the screen line (7). Other cities, such as London and Atlanta, have had much less success gaining cooperation from firms and employees (8). In these cases, impacts on traffic can be expected to fall short of the Ottawa experience.

Carpooling Programs

The most successful carpooling programs provide incentives for ride sharing, such as preferential access to toll gates and reduced parking charges. Evaluations of the traffic impacts of these programs are scarce, but we may deduce that the effects tend to be small. Preferential lane treatment in the case of the San Francisco-Oakland Bay Bridge increased pooling by 80 percent. However, poolers still constitute less than 10 percent of the vehicles on this bridge (9), and trends in traffic growth on the bridge remain largely unaltered. One reason to expect small impacts on traffic has to do with the previous mode of poolers. In Seattle, a discount parking program for poolers attracted most of its new poolers from transit riders (40 percent) and previous carpoolers (38 percent) (10).

Traffic Management

Traffic management techniques, including directional controls, striping, and channelization, can reduce localized traffic densities, but long-lasting or areawide improvements cannot be expected (11). At best, methods of improving traffic flows, such as through conversions to one-way streets, help one direction but hinder another. Some signalization computer systems reduce densities and improve flow, but improvements are expected to last only a few years (12, 13).

Transit-Fare Changes

Fare reductions on transit reduce automobile trips somewhat, but an early study (14) shows that cross elasticities are about -0.138 for work trips where dense traffic is most likely to be encountered. This means that a reduction of 10 percent in transit fares reduces automobile trips by only 1.38 percent, all else being held constant. Studies on actual transit-fare reductions and their impacts on traffic are not numerous. One extensive study in Los Angeles (15) could not detect traffic impacts because of fare reductions, impacts beyond those attributable to random variations in traffic, and the effects of the 1974 gasoline shortage.

PERCEPTIONS OF POLICYMAKERS

The Urban Institute and its consultants have presented information on area licenses to U.S. cities during the last three years, seeking a site for an area license demonstration in which, for as long as two years, the Urban Mass Transportation Administration (UMTA) would pay for preplanning, permits, enforcement, administration, transit expansion (e.g., bus and lot leases for park-and-ride), signs, information materials, and evaluation. At least 15 cities have thus far received information on the license plan by way of letters from the Secretary of Transportation, information packets, and formal and informal meetings. Some of the cities, such as Boston, obviously suffer from dense traffic. In others, such as Berkeley, California, traffic densities are less severe but there is no less concern for traffic problems. In only three of the cities contacted (Berkeley, Madison, and Honolulu) have decision makers requested preliminary study of a license approach. These studies were intended to examine the traffic impacts of alternative prices for certain problem areas and to determine whether a self-sufficient program was feasible. In each of these cities, the studies were abandoned before completion because of objections from the public at large, the business community, and key decision makers. Of the preliminary studies done in Berkeley; Madison, Wisconsin; and Honolulu, those by Spielbert (16) and Cheslow (17) are in published form.

Objections did not center primarily on study findings, on participation in a federally sponsored demonstration, or on major misconceptions (although the press occasionally suggested that toll booths might dot the city). Instead, brief post mortem studies showed that major objections involved conceptual and implementation issues. These were raised in the study cities and in responses from cities that refused the UMTA offer for preliminary study. The major objections—those that alone or together stopped the studies—and the more minor objections—those that created skepticism about the concept but were not sufficient to halt further study—are summarized below:

1. Major objections—(a) interferes with right to travel, (b) harms business or business image, and (c) discriminates against the poor.
2. Minor objections—(a) hard to enforce, (b) overloads transit facilities, (c) relocates traffic problems, and (d) requires legislative clearance.

ACCOUNTING FOR PERCEPTIONS OF ADVERSE IMPACTS

What is the typical response of analysts to perceptions of the possible impacts of road pricing such as those given above? Some analysts and economists would simply say that certain objections about impacts are in a realm of ethics or politics that is not approachable by analysis. Discrimination against the poor, harm to the business image, and interference with the right to travel might fit this realm. The argument goes that some impacts cannot be defined or quantified, are purely speculative, or in any case should only be debated and accounted for in the political arena. Yet, this argument fails to take into consideration that analysis must deal with perceptions relevant to decision makers if the concept in question is to get a fair chance at implementation and testing. With implementation in mind, the analysis should go as far as possible toward defining politically sensitive issues, analyzing possible impacts, and, if possible, suggesting ways to guard against adverse impacts.

It was from this position that analysts at the Urban Institute approached the task of studying the possible impacts of road pricing in interested cities. They produced not only the usual projections of traffic, transit, and revenue impacts for the study cities but also certain issue papers, memoranda, and informal presentations on more difficult and sensitive issues. Thus, there were attempts to define and analyze distributional effects of area licenses in a sample of U.S. cities and efforts to analyze legal issues behind the concern for legislative clearance. Projections were made as to the number of enforcers needed and their cost and how program costs compared with revenues. Modeling efforts were undertaken to project possible diversions of work and shopping trips away from the priced zones.

Information about enforcement and impacts on shopping, costs, and revenues in the Singapore scheme was also relayed to the study cities. Staff and decision makers were told that the number of shopping trips to the Singapore priced zone did not decrease as a result of changes in the various transportation measures, although a household survey showed a decline of roughly 5 percent, which was probably the result of increased parking charges and not the license. This finding is confirmed by interviews with the business community. Wholesalers and retailers report that they have benefited from faster goods delivery. Also mentioned was the fact that the plan is enforceable (2-4 monitors are stationed at each entry point, and violations are not excessive) and that revenues from the license sales exceed the costs of enforcement, permit printing, and distribution by about S$500 000/month.

Unfortunately, these attempts to make the analysis as relevant as possible to the perceptions of possible adverse impacts were not successful in getting a trial for road pricing. Why? Not because the analysis had infringed on inappropriate political territory. On the contrary, the analysis of probable and possible impacts was on the right track in its attempt to deal with issues most crucial to the concept implementation. Nor was the problem that these impacts could not be addressed analytically. The nub of the problem was that the analysis focused too much on the probability of occurrence of the impacts rather than on demonstration designs that protect against and compensate for adverse impacts should they occur.

FROM IMPACT ANALYSIS TO CONTINGENCY PLANNING

As cities refused to proceed with further study of road pricing because of one or more of the objections given in the list above, the need for contingency planning became more apparent. For example, take the objection that area licenses discriminate against the poor. The study team offered to do an analysis on this issue to determine how the costs and benefits of alternative pricing programs would be distributed among travelers by income group. In addition, reference was made to work already done for the cities of Washington, D.C., Boston, and San Francisco, which showed that area licenses created regressive gains and losses of travel time across income groups of travelers but suggested remedial steps to distribute revenues to modes or projects that would directly benefit the poor. [According to Kulash (18), a hypothetical area license system for Washington, D.C., would provide travel-time benefits to 36.7 percent of travelers who have incomes less than $3172 and to 50 percent of those who have incomes greater than $6347 (based on 1970 travel and income patterns).] Yet it was not such analysis that was needed, as the case of Madison suggested. A planning commission member there indicated that he would not have voted to halt the area license study as he did if the plan could have been designed so that the public would judge it to be progressive. Given strong public perceptions on the subject, the commissioner was seeking not analysis but assurance that the area license demonstration could be designed to avoid certain perceived problems or meet such problems should they arise. How could the demonstration be made visibly progressive? And if it were not perceived as such, how could it be changed in midstream to meet public perceptions?

The importance of specific demonstration designs that account for possible adverse outcomes, as opposed to analysis of the likelihood of these problems occurring, was reiterated in discussions of the more minor objections. Evidence of how enforcement proceeded in Singapore, for example, turned out to be unconvincing in the study cities. The prospect of an enforcement force monitoring a moving stream of traffic was overwhelming to traffic enforcement officers. Perhaps more important, state laws often oblige traffic enforcement personnel to cite vehicle drivers, not owners, for moving violations, and this raised the prospect of litigation should any demonstration attempt to emulate the Singapore system of mailing citations to registered owners. Although in most U.S. cities parking violations are handled without presenting a citation directly to the driver, moving violations are not generally handled in this way. Would state law have to be changed prior to a demonstration? Could demonstration funds be used to assist a city with litigation costs that might arise on this issue or others?

Discussion of the remaining, more minor, objections again centered around possible worst cases and their consequence. Some city officials agreed that transit might not be overloaded if federal capital grants were forthcoming at the right time and in sufficient amounts. Yet transit managers in each of the study cities complained of strained storage and maintenance facilities that could not handle significant increases in transit. How would these costs be managed? Objections to relocating traffic were raised in both Berkeley and Madison. In Berkeley, the concern was that fewer people than the analysis predicted might switch to transit and instead switch to driving through neighborhoods outside the priced zone. (The preliminary study results for Berkeley indicated that a peak pricing plan for one troubled area, the Tunnel Road vicinity, might reduce peak traffic by 29 percent. The plan involved 1500 park-and-ride spaces, 18 buses running 12 h/day, and a license price of $1.00/day. Revenues from pricing and bus fares were projected to be $1.76 million annually, more than sufficient to meet the transit, parking, and administration costs of $1.56 million.) In Madison, the concern was that there were no routes around a congested zone that would be most logical for pricing. The need for contingency planning was obvious. Some Madison city staff believed ways might be found to make street conversions that would create a free artery through the priced zone. In Berkeley, there was discussion about expanding zone boundaries during the demonstration to protect any neighborhoods that might suffer from traffic circumventing the priced zone.

Clearly, not all of the objections cited earlier about adverse impacts point to the need for contingency planning. An example is the right-to-travel objection. Some city council members comment that motorists have come to consider road use as a right paid for through current user fees such as gasoline taxes and vehicle registration and that these fees already make up motorists' "fair" contribution to road and highway systems. Analysis might demonstrate the "unfairness" of the current system of highway financing when more capital, maintenance, and external costs (e.g., pollution and congestion) are attributable to peak than to off-peak use and yet use is not priced to reflect the cost difference. It might suggest road tolls, at certain times and places, to reflect the full costs of road use. However, it is hard to imagine any contingency planning that might satisfy the concern about unfair financing impacts if the current system of costs and benefits is considered fair.

Nor does the question of clearance obviously point to contingency planning. Decision makers in all three study cities expressed some concern about the need for state authorization to tax the use of city streets. The 10th Amendment to the U.S. Constitution gives states the right to decide which taxes will and will not be allowed within their jurisdictions. It appears that some cities have already been given sufficiently broad taxing powers to allow road user charges. [Section 1642(4) of the vehicle and traffic law of the state of New York allows the city of New York to charge tolls, taxes, fees, licenses, or permits for highway use, and the Illinois state constitution gives Chicago partial home rule in the selection of ways to raise revenues, although it disallows taxes on income or occupation. Further discussion of legal issues surrounding roadway pricing can be found elsewhere (19).] Yet, as a practical matter, decision makers in the study cities believed they either should or would be obliged (by political pressure or suit) to approach the legislature. This prospect did not sit comfortably with decision makers in at least two of the three cities because of the delay, bantering, and battles involved in such actions. It seems unlikely that any demonstration designs could help in the case in which legislative clearance became a burden.

SPECIFIC CONTINGENCY PLANS FOR ROAD PRICING

Although not all perceptions of adverse impacts may be amenable to contingency planning, some of the most troublesome are. To the extent that these perceptions stand in the way of implementation, contingency plans to cope with adverse impacts, should they arise, bring road pricing this much closer to implementation. The important point here is the need to take into account certain perceptions of adverse impacts and analyze and suggest ways to manage or compensate for such impacts should the need arise. This is the emphasis that is needed as a complement to traditional impact analyses of road pricing or other automobile restraints where the perceptions of affected parties are at odds with those of the analyst.

What are examples of this kind of thinking as applied to road pricing? Within the federal demonstration format, much might be done to guard against certain risks and share others. For instance, in the demonstration contract between the federal government and cities, provision might be made to allow the project period to be short-term and renewable instead of the 12- to 24-month commitment commonly used. A contingency account might be agreed to at the outset that would be triggered to assist the city to end the program and return to normal operations should the project have to be halted before significant revenues are generated. The contract might also spell out a federal role in sharing any litigation expenses that arise in relation to the program. Certainly the contract should allow the city to modify zone boundaries, the sticker price, and hours of application so as to prevent harm to certain businesses or to cope with spillover traffic. It might also allow the city to negotiate for a share in the license revenues of commuter-serving transit with surrounding jurisdictions or districts where much commuter traffic originates.

What might be done about objections to road pricing that are based on concern about business impacts? One possibility that is not particularly attractive to federal demonstration sponsors is to specify in the contract a federal role in compensating damages to certain third parties in the priced zone. Federal research and development contract provisions present a cost-reimbursement model that has possible applications for demonstration purposes. The research and development contractor is required to procure certain liability insurance for performance of contract work and is reimbursed for a portion of the insurance costs. The federal government assumes liability for third-party losses not compensated for by contractor insurance, provided that liabilities are represented by final judgments or settlements approved in writing by the government. (Excepted are liabilities for which the contractor is responsible under the contract agreement or whereby the contractor has engaged in "willful misconduct". In practice, when claims made against contractors are uninsured or exceed the amount of contractor coverage, the contractor usually authorizes government representatives to settle or defend such claims and represent the contractor unless the contractor, at his or her own expense, wishes to associate with government representatives in settlement or defense.) Federal demonstrations could use a version of this model by requiring municipal insurance of the participating city and the federal government itself to assume liability for losses that exceed city insurance coverage.

Is there a precedent for such insurance or compensation arrangement in any demonstration programs? In fact, there is, but not on the scale that might be necessary in a road-pricing demonstration. UMTA has agreed with a few taxi companies to ensure that revenues do not fall below some negotiated baseline during certain transit demonstrations. But doing the same thing for a host of downtown retail and parking businesses may involve more haggling and monitoring than federal program managers wish to take on.

How might the possible regressive impacts of road pricing be handled? Again, less attention should be paid to whether or not a plan will be regressive and more to various compensation contingencies that would meet local objections if and when they arise. In all of the study cities, community organizations that represent the poor could have been asked about transportation or other public service improvements to accompany the plan. This may or may not have worked to meet objections, but it would have been the place to begin.

BEYOND CONTINGENCY PLANNING

When the perceptions of affected parties about adverse impacts are such that no amount of impact analysis or contingency planning can effect implementation, what then? After all, contingency planning can go only so far in meeting the worst-case concerns of decision makers and their constituencies. Beyond some point, it is simply more trouble to live with a federal demonstration package, with all its associated contingency clauses, disaster funds, and the like, than it is to live with problems related to dense traffic. In such a case, the concept itself may have to be altered—no more, one hopes, than necessary to achieve implementation and to learn some of the things sought in the original concept.

Is parking pricing a good second best? When through traffic is not a major part of the traffic problem, certain parking-pricing policies might generate some of the same information as a road-pricing demonstration and lead the way to future area licenses. For example, requiring priced permits for parked vehicles in congested zones during peak periods might provide valuable lessons about permit distribution, administration, revenue generation, and enforcement. Permits for hourly and multihourly parking, variable by price, have been developed and tested in Tel Aviv. The system has replaced the use of street meters there. Several coastal communities in California that experience a heavy influx of summer traffic have recently received grants from UMTA to experiment with priced parking permits for nonresidents coupled with park-and-ride facilities. If and when recreational communities find the use of priced permits for parked vehicles successful, perhaps it will not be so difficult for one of these same communities—and then urban areas—to require permits on moving vehicles.

CONCLUSIONS

Where automobile restraints are the subject of impact studies and analysis, the analyst is well advised not to discount the perceptions of policymakers, interest groups, and the public in conducting the analysis. On the contrary, analysis should focus on these perceptions and try to define, quantify, and inform the debate on them. Furthermore, even the most relevant impact analysis may have to yield to contingency planning where the analysis is unable to meet certain concerns about impacts. Finally, where neither impact analysis nor contingency planning is able to move the restraint concept toward implementation, the concept itself will probably need to be altered.

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Relative Accuracy of User-Benefit Measures

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The rigorous application of cost-benefit analysis is an important aid in transportation policy and project decision making. However, any computation of changes in consumer surplus in the cost-benefit calculus will at best be an approximation of the true user benefit. Thus, it is useful to examine which approximations are the most accurate and whether increased precision in user-benefit estimates is worth the extra computational burden. Demand model misspecification is shown to lead to greater errors in policy evaluation than does simple linear approximation of the true demand curve. The following conclusions are reached: (a) With the advent of improved travel forecasting techniques, consumer's surplus measures in cost-benefit analysis are theoretically justifiable in transportation planning; (b) the computational costs of estimating changes in consumer surplus are small in relation to the useful information gained from the exercise; and (c) the major potential source of error in estimating change in consumer surplus is likely to arise from inaccurate travel demand estimates and models rather than from the algorithm used in the computation of consumer surplus.

Highly relevant and valid cost-benefit studies are rarely attained in transportation analysis. The many impacts of a large-scale system improvement often defy formulation in monetary terms. Cost-benefit computations are often done improperly, benefits are double counted as user and nonuser impacts, transfer payments are included as costs or benefits, and labor costs are counted as benefits (1). Even when cost-benefit studies are included as part of feasibility studies, their role is subservient to other factors related to the local political process (2).

These problems, as well as legislated requirements for the National Environmental Policy Act review of transportation projects, have led to consideration of a profusion of other impact measures associated with transportation feasibility studies. The current recommendations indicate that more than 40 different user- and non-user-related impact categories should be addressed in evaluation studies, such as that by Manheim and others (3). Each category will have several different measures, including a relatively refined distributional component across various demographic segments. Compounding the problem is the large number of alternative projects that would require investigation; a current suggestion for alternatives-analysis procedures to secure Urban Mass Transportation Administration (UMTA) funding involves detailed evaluations of 5-10 alternatives drawn from a list of 40-60 alternatives evaluated in an initial phase (4). Even though experience with alternatives-analysis procedures is limited, municipal planning organizations have claimed that "communicating, comparing, and aggregating impact measures" are "key issues of concern" (4).

Recently, transportation researchers have shown how probability choice models of travel behavior can give conceptually elegant and easily computed summary measures of user impacts. For example, Williams (5) has shown how multinomial logit, generalized to account for correlated error terms, can be used to compute precise measures of consumer surplus in the traditional four-step urban transportation planning system process. Ben-Akiva and Lerman (6) demonstrated how these measures of consumer surplus correspond to a rigorously defined measure of accessibility, which itself is a primary objective of transportation planning and policy. Sheffi (7) has shown how these measures can be computed from random-coefficient multinomial probit models to determine how projects improve network performance. Small (8) has used consumer surplus derived from logit modeling with a queuing model of highway performance to evaluate various transportation system management (TSM) strategies.

Given these theoretical advances, it is worth considering whether cost-benefit analysis should be reconsidered as a method of providing summary measures of impacts in transportation evaluation studies. To the extent that cost-benefit computations can substitute for a larger number of other impact measures purportedly aimed at community goals, social welfare, and investment criteria, such analyses could potentially lead to more rational project and policy selection with less analytical effort.

This paper attempts to resolve some questions about the application of disaggregate probability choice models to cost-benefit analysis. The first issue is theoretical: Is the measure of consumer surplus from probability choice theory an intuitively meaningful representation of user impacts? The next issue addressed is practicality: What is the extra computation and analysis burden of cost-benefit analysis with probability choice models? Finally, the empirical problem of accuracy is considered: Is the precise measure of consumer surplus from probability choice models significantly different from the commonly used aggregate linear approximations? Although most of the above questions can be answered theoretically, we have also included in a separate section empirical simulation tests of the potential gains in accuracy from disaggregate probability choice cost-benefit analysis.

THEORY

The purpose of cost-benefit analysis is to measure social welfare gains (or losses) and their distribution attributable to specific projects and policies. The development of cost-benefit analysis relied on the somewhat ambiguous concept of consumer surplus from economic theory (9). Although this concept is also used here, an intuitively plausible argument for cost-benefit analysis can be developed from other paradigms of household behavior, such as willingness to pay, revealed preference, consumer trade-offs, and opportunity costs. It should also be noted that there are differences in the conceptualization of consumer surplus between probability choice behavior and traditional economic demand theory. If probability choice theory is a good representation of the individual transportation decision-making process, then some of the arguments against cost-benefit analysis that are based on traditional economic theory are no longer valid.

Consumer surplus can be described by first considering only price and quantity relations. Among those who purchase a good or service, there are those who benefit because the good or service is worth more to them than the asking price; as the price rises, these people would still choose to make their original purchase. The amount of this benefit is the consumer surplus. When prices are changed, the consumer surplus also changes. For example, when transit fares are lowered, those who formerly took transit, and continue to do so at the same rate, receive a benefit per trip by the amount of the reduction of the fare. There is also a consumer surplus change for new patrons, but calculating its value is more subtle. The change in such users' consumer surplus is the amount by which the worth of a transit trip to transit users exceeds the fare. For an individual, this requires knowing to which fare the person is indifferent in relation to switching from some other mode to transit. However, because such a fare level never really occurred, for most individuals it is necessary to infer this point of indifference from a demand model.

In mode-choice decisions, individuals make choices based on several attributes or level-of-service (supply) characteristics in addition to price. Policy evaluation must account for the benefits that accrue when such attributes are changed. The typical probability choice model assumes that, for each individual and each mode (e.g., transit or automobile), one can formulate a linear combination of these attributes and price into some inclusive cost I_j for mode j. This inclusive cost is dimensionless; in the transportation literature it is most often defined as utility, although identical probability choice models can be developed from other precepts [a discussion of the difference between utility in probabilistic decision analysis and utility in economic demand analysis is given by Luce and Raiffa (10)].

The inclusive cost must have behavioral content when it is constructed, and it should include all attributes of modes that affect transportation decision making. The weights on these attributes should be such that the mode with the lowest cost is the one actually chosen. That is, if there are N attributes h_{ij} for mode j with weights or coefficients θ_i, then for

$$I_j = \sum_{i=1}^{N} \theta_i h_{ij} \tag{1}$$

the θ_i have values such that, if $I_j < I_k$, then mode j is chosen for any two modes k and j $(j \neq k)$. If the θ_i meet this test, they show the trade-offs an individual makes across modal attributes.

If such an index of inclusive cost satisfying the above behavioral criteria could be estimated with certainty for all individuals, then we would be able to construct very simple and powerful cost-benefit measures. Suppose a policy changes the attributes of various modes. Then the monetized per-trip values of the change in consumer surplus across a population of individuals is simply

$$\$\Delta CS = \sum_{t=1}^{T} (I'_{jt} - I''_{kt})/\theta_{ot} \tag{2}$$

where

$\$\Delta CS$ = change in consumer surplus ($),
I'_{jt} = inclusive cost of mode chosen by the tth individual before the change in attributes,
I''_{kt} = inclusive cost of mode chosen by the tth individual after the change in modal attributes (j may equal k), and
θ_{ot} = coefficient on price in the inclusive cost for the tth individual.

The major problems with using the above relationships tend to be practical rather than theoretical. Our powers of observation do not allow us to determine Equation 1 with certainty for each individual. To help overcome this deficiency, it is common practice to make probabilistic statements about individual behavior by using well-defined probability choice models.

The most common probability choice model uses the multinomial logit functional form. In terms of inclusive prices, this model can be written as follows:

$$P_{jt} = \exp(-I_{jt}) / \sum_{m=1}^{M} \exp(-I_{mt}) \tag{3}$$

where P_{jt} = probability of an individual t choosing the jth among M alternatives.

ANALYTIC FORMS FOR CHANGES IN CONSUMER SURPLUS

Probability choice models add realism to travel demand models, but they complicate the mathematical derivation of changes in consumer surplus. The following calculations show how changes in consumer surplus are calculated from probability choice models generally and from multinomial logit models specifically.

Binomial Probability Choice Model

Suppose that the original costs of modes 1 and 2 are I_1' and I_2', respectively. Now consider an arbitrary individual's consumer surplus for use of mode 1. Let $P_1' = P_1(I_1', I_2')$, and define the characteristic function

$$C_{(I_1',\infty)}(I_1) = \begin{cases} 1 \text{ if } I_1 > I_1' \\ 0 \text{ otherwise} \end{cases} \quad (4)$$

If mode 1 is worth I_1 to the individual in terms of willingness to pay, with $I_1 > I_1'$, and its cost is only I_1', this amounts to $I_1 - I_1'$ in consumer surplus. Because behavior in response to I_1 is probabilistic, the value of I_1 can also be viewed as probabilistic. Consequently, the consumer surplus is the expected value of this quantity, or

$$CS_1' = E[(I_1 - I_1')\, C_{(I_1',\infty)}(I_1)|I_2'] = \int_0^{P_1'} (I_1 - I_1')\, dP_1 \quad (5)$$

Note that I_1 is a function of P_1 (with I_2' fixed) and that $I_1 > I_1'$ if and only if $P_1 < P_1'$. A more useful expression is obtained by integrating by parts:

$$\int_0^{P_1'} (I_1 - I_1')\, dP_1 = (I_1 - I_1')\, P_1 \Big|_0^{P_1'} - \int_\infty^{I_1'} P_1(I_1, I_2')\, dI_1$$

$$= \int_{I_1'}^{\infty} P_1(I_1, I_2')\, dI_1 \quad (6)$$

Similarly, the consumer surplus for use of mode 1, when its cost becomes I_1'', is

$$CS_1'' = E[(I_1 - I_1'')\, C_{(I_1'',\infty)}|I_2'] = \int_{I_1''}^{\infty} P_1(I_1, I_2')\, dI_1 \quad (7)$$

so that the change in consumer surplus is

$$\Delta CS_1 = \int_{I_1''}^{\infty} P_1(I_1, I_2')\, dI_1 - \int_{I_1'}^{\infty} P(I_1, I_2)\, dI_1$$

$$= \int_{I_1''}^{I_1'} P_1(I_1, I_2)\, dI_1 \quad (8)$$

If, then, the cost of mode 2 is changed to I_2'', the change in consumer surplus for use of mode 2 is

$$\Delta CS_2 = \int_{I_2''}^{I_2'} P_2(I_1'', I_2)\, dI_2 \quad (9)$$

so that the total change in consumer surplus from both changes in cost is

$$\Delta CS_{12} = \Delta CS_1 + \Delta CS_2 = \int_{I_1''}^{I_1'} P_1(I_1, I_2')\, dI_1$$

$$+ \int_{I_2''}^{I_2'} P_2(I_1'', I_2)\, dI_2 \quad (10)$$

If the cost of mode 2 is first changed from I_2' to I_2'' and then the cost of mode 1 is changed from I_1' to I_1'', the total change in consumer surplus is

$$\Delta CS_{21} = \int_{I_2''}^{I_2'} P_2(I_1', I_2)\, dI_2 + \int_{I_1''}^{I_1'} P_1(I_1, I_2'')\, dI_1 \quad (11)$$

The change in consumer surplus should be independent of the order of changes in costs; that is, it would be reasonable for ΔCS_{12} to equal ΔCS_{21}. Since P_1 and P_2 are functions only of $I = I_1 - I_2$ and since $P_2 = 1 - P_1$, it can be seen that

$$\Delta CS_{12} = \int_{I_1'' - I_2'}^{I_1' - I_2'} P_1(I)\, dI - \int_{I_1'' - I_2''}^{I_1'' - I_2'} P_2(I)\, dI$$

$$= \int_{I_1'' - I_2'}^{I_1' - I_2'} P_1(I)\, dI + \int_{I_1'' - I_2''}^{I_1'' - I_2'} P_1(I)\, dI - I \Big|_{I_1'' - I_2''}^{I_1'' - I_2'}$$

$$= \int_{I_1'' - I_2''}^{I_1' - I_2'} P_1(I)\, dI + I_2' - I_2'' \quad (12)$$

$$\Delta CS_{21} = -\int_{I_1' - I_2''}^{I_1' - I_2'} P_2(I)\, dI + \int_{I_1'' - I_2''}^{I_1' - I_2''} P_1(I)\, dI$$

$$= \int_{I_1' - I_2''}^{I_1' - I_2'} P_1(I)\, dI + \int_{I_1'' - I_2''}^{I_1' - I_2''} P_1(I)\, dI - I \Big|_{I_1' - I_2''}^{I_1' - I_2'}$$

$$= \int_{I_1'' - I_2''}^{I_1' - I_2'} P_1(I)\, dI + I_2' - I_2'' \quad (13)$$

so that $\Delta CS_{12} = \Delta CS_{21}$.

Binomial Logit Model

Consider a logit model for choice between transit and automobile modes, and calculate the change in consumer surplus when transit cost changes from I_t' to I_t'' and automobile cost changes from I_a' to I_a'':

$$\Delta CS = \int_{I_t'' - I_a''}^{I_t' - I_a'} P_t(I)\, dI + I_a' - I_a''$$

$$= \int_{I''}^{I'} [1/(1 + e^I)]\, dI + I_a' - I_a''$$

$$= \int_{e^{I''}}^{e^{I'}} [1/x(1 + x)]\, dx + I_a' - I_a''$$

$$= [\ln x - \ln(1 + x)] \Big|_{e^{I''}}^{e^{I'}} + I_a' - I_a''$$

$$= I' - I'' + \ln[(1 + e^{I''})/(1 + e^{I'})] + I_a' - I_a''$$

$$= \ln(P_t'/P_t'') + I_t' - I_t'' \quad (14)$$

letting $x = e^I$.

Multinomial Logit Model

The preceding calculation of consumer surplus can be easily generalized to the multinomial case. Consider several modes $k = 1, 2, \ldots, N$ with costs I_k and mode-choice probabilities $P_k = \exp(-I_k)/\sum_{j=1}^{N} \exp(-I_j)$. Suppose original costs are I_j', $j = 1, 2, \ldots, N$. The change in consumer surplus from changing the cost of mode 1 from I_1' to I_1'' is

$$\Delta CS_1 = \int_{I_1''}^{I_1'} P_1(I_1, I_2', \ldots, I_N')\, dI_1$$
$$= \int_{I_1''}^{I_1'} \left\{ \exp(-I_1) \Big/ \left[\exp(-I_1) + \sum_{j=2}^{N} \exp(-I_j') \right] \right\} dI_1$$
$$= \int_{\exp(-I_1'')}^{\exp(-I_1')} \left\{ -1 \Big/ \left[x + \sum_{j=2}^{N} \exp(-I_j') \right] \right\} dx$$
$$= \left\{ -\ln \left[x + \sum_{j=2}^{N} \exp(-I_j') \right] \right\}_{\exp(-I_1'')}^{\exp(-I_1')}$$
$$= \ln \left\{ \left[\exp(-I_1'') + \sum_{j=2}^{N} \exp(-I_j') \right] \Big/ \sum_{j=1}^{N} \exp(-I_j') \right\} \tag{15}$$

letting $x = e^{I'}$. If we then change the cost of mode 2 to I_2'', the change in consumer surplus is

$$\Delta CS_2 = \ln \left\{ \left[\exp(-I_1'') + \exp(-I_2'') + \sum_{j=3}^{N} \exp(-I_j') \right] \div \left[\exp(-I_1'') + \sum_{j=2}^{N} \exp(-I_j') \right] \right\} \tag{16}$$

If all of the cost is changed to I_j'', j = 1, 2, ..., N, and all of the ΔCS_j's are added, the result is

$$\Delta CS = \ln \left[\sum_{j=1}^{N} \exp(-I_j'') \Big/ \sum_{j=1}^{N} \exp(-I_j') \right] \tag{17}$$

Fortunately, as the equations above show, the change in consumer surplus from a multinomial logit model is a relatively simple function:

$$\$\Delta CSL = \sum_{t=1}^{T} (1/\theta_{ot}) \left\{ \ln \left[\sum_{m=1}^{M} \exp(-I_{mt}') \right] - \ln \left[\sum_{m=1}^{M} \exp(-I_{mt}'') \right] \right\} \tag{18}$$

where $\$\Delta CSL$ = change in consumer surplus over a population of T individuals in dollar terms.

Equation 18 is the difference between the log of the denominators from Equation 3 before and after the policy-induced changes in modal attributes. Notice that it resembles Equation 3 except that all modes are represented, including those not chosen. However, if a mode has a low probability of being chosen because it has a relatively large inclusive cost, its contribution to $\$\Delta CSL$ is relatively slight.

In general, Equation 18 weights the change in inclusive cost by the probability of a mode being chosen. To see this, suppose that a policy only changes the inclusive price of a single mode j. Equation 18 can be rewritten in terms of the probability of choosing j, as follows:

$$\$\Delta CSL = \sum_{t=1}^{T} (1/\theta_{ot}) \{ \ln [P_{jt}' \exp(I_{jt}')] - \ln [P_{jt}'' \exp(I_{jt}'')] \} \tag{19}$$

This nonlinear weighting scheme, which is rigorously derived from the multinomial logit model, is a plausible method for computing changes in user benefits.

RESULTS

Two conclusions emerge from the above discussion and analytic forms. First, computation of consumer benefits requires little extra effort if a probability choice framework is already being used in travel demand analysis. All of the information needed to compute ΔCSL, by use of either Equation 18 or 19, is available from the travel forecasting exercise. The second issue involves the reasonableness of using changes in consumer surplus as a measure of user impacts. We feel that, with advances in behavioral modeling, many of the old arguments against cost-benefit analysis have lost their validity. In particular, the probability choice models can consider a wide range of transportation attributes and choices that affect user well-being and can be estimated on separate market segments; the result is that distributional issues can be addressed with more precision.

These conclusions are not uncontroversial. Common arguments against using consumer surplus and, consequently, cost-benefit analysis can be classified as follows:

1. Demand models do not include enough transportation attributes that affect behavior and that consequently affect computations of user benefits.
2. Nonuser benefits and disbenefits are not included by definition.
3. Distributional issues are not addressed.

The final determination of whether cost-benefit analysis should be applied is whether the extra information gained is worth the effort of computation. If consumer surplus changes are a starting point for impact evaluation, then some of the perceived problems with the approach must be put into a different perspective. For example, because most nonuser benefits are transfers of user benefits (11), it is appropriate to compute user benefits before analyzing nonuser impacts. Demand estimation is also needed to evaluate the impacts of nonuser disbenefits such as air pollution and oil consumption, which are externalities, since they are often the result of flow-related variables. Distributional issues require disaggregating the data and tracing the incidence of transfers of benefits and disbenefits so that, again, travel demand and user benefits are required as a building block.

The argument that demand models are inadequate to support accurate cost-benefit analysis perhaps misses the point. Decision makers require some notion of project cost-effectiveness in order to choose among alternative transportation options. We should use as much information as is feasible in evaluating these choices. Uncertainty in the evaluation process that arises from errors in demand models should also be specified. This contradicts the recommendation that one should not use all of the information from the demand models because they contain errors.

COMPARISONS AMONG APPROACHES

The final question we wish to address is whether disaggregate probability choice measures of user benefit (changes in consumer surplus) are substantially different from more traditional measures based on linear approximations. For purposes of comparison, a simple simulation experiment based on application of a multinomial logit work-trip mode-split model is applied to Boston data. The findings indicate that different methods for computing user benefits will give different results but that these differences are neither major nor systematic.

The three traditional approaches to user benefits are described briefly below.

Trapezoid

A reasonable approximation to consumer surplus measures involves an implied linear approximation to the aggregate demand curve. Within the context of mode-choice behavior, the trapezoidal measure can be expressed as follows:

$$\$\Delta CST = (1/2)\sum_{m=1}^{M} (D'_m + D''_m)(\bar{I}'_m - \bar{I}''_m) \quad (20)$$

where

$\$\Delta CST$ = aggregate change in consumer surplus over a region ($),
D'_m = aggregate demand for mode m prior to change induced by a policy,
D''_m = aggregate demand for mode m after the policy is imposed,
$\bar{I}'_m$ = weighted average of inclusive cost in money units across individuals in the region before the policy is imposed, and
$\bar{I}''_m$ = weighted average of inclusive cost in money units across individuals in the region after the policy is imposed.

Equation 20 can be derived from Hotelling's generalized consumer surplus form by using a Taylor's series expansion about the demand curve (5, 12).

Automobile-Drive-Alone Trapezoid

A common approach in early highway impact and feasibility studies was to compute user benefits based on the automobile-drive-alone mode. Even assuming that the highway project had no impact on bus travel, this approach excluded changes in carpooling behavior that may have resulted in benefits or costs. The approach is a special case of Equation 20:

$$\$\Delta CST_a = (1/2)(D'_a + D''_a)(\bar{I}'_a - \bar{I}''_a) \quad (21)$$

where the subscript a refers to the automobile-drive-alone mode.

Value of Time

Another special case of Equation 20 is the traditional computation of value of time saved. This can be written as follows:

$$VOT = (1/2)\sum_{m=1}^{M} (D'_m + D''_m)(\bar{C}'_m - \bar{C}''_m) + \bar{\theta}_{mi}(\bar{T}'_m - \bar{T}''_m) \quad (22)$$

where

VOT = aggregate value-of-time change as a result of a policy,
$\bar{C}'_m$ = average money cost of mode m across users before the policy,
$\bar{C}''_m$ = average money cost of mode m across users after the policy,
$\bar{\theta}_{mi}$ = average value per unit of trip time across users,
$\bar{T}'_m$ = average trip time of mode m across users before the policy, and
$\bar{T}''_m$ = average trip time of mode m across users after the policy.

Typically, $\bar{\theta}_{mi}$ is a function of the user's income. In addition, trip time is often decomposed into separate elements, such as walk, wait, and line-haul time, to each of which different θ-weights are attached.

Theoretically, the potential error in using trapezoidal approximations can be substantial. Figure 1 shows an example. The ogive-shaped curve in the figure is presumed to be the actual demand relationship for the region. The shaded area is the magnitude of consumer surplus underrepresented by computing the area of the trapezoid $I''_a deI'_a$. If $\bar{I}''_a - \bar{I}'_a$ is a tax, then the actual social welfare change is approximated by the triangle def and, although the absolute error remains the same, the relative magnitude of error is substantially larger. In general, if the probability choice model has sharp curves and the policy induces substantial mode switching, then the linear approximation is likely to be significantly in error. These circumstances are most likely to occur when there is a homogeneous population and the model provides a good fit to the data.

As a practical matter, there may be times when analysts will only have the data required for Equations 20-22 rather than the formal model implied for Equations 18 and 19. Assuming that the probability choice model is a correct representation of individual behavior, the question naturally arises as to the magnitude of error that can be expected from using trapezoidal approximations.

To give an indication of the possible differences in user-benefit calculations, several simulation experiments were performed on transportation control strategies and transit improvements for Boston's North Shore corridor. An existing multinomial logit model of choice of mode to work was calibrated on a household survey collected in 1973. The model forecasts automobile-drive-alone, transit, and four automobile multipassenger modes. Details of the model calibration and its expansion to aggregate forecasts are presented elsewhere (13).

Two sets of simulations were performed: The first set involves three automobile-travel pricing policies aimed at restraining peak-hour commuting to and from the downtown; the second set involves various combinations of automobile restraints and transit improvements for downtown commuters. The results of the automobile pricing strategies are reported first.

The social welfare impacts of automobile price increases include the resource costs of administering the program and the opportunity cost of automobile travel forgone because of higher trip costs. Although prices actually paid (the area of the rectangle $I''_a dfI'_a$ in Figure 1) are user costs, they are transfer payments rather than resource costs. Thus, cost-benefit analysis of price strategies requires, most importantly, an accounting of the area bounded by points def in Figure 1.

The three pricing policies simulated were an increase in bridge and tunnel tolls to the downtown of \$0.75 one way; a parking surcharge for all downtown employees of \$1.50/day; and a regionwide gasoline tax of 75 percent of the 1973 pump price, which was equivalent to \$0.014/km (\$0.0227/mile), given the average fuel economy of the 1973 fleet. Three computations of opportunity cost effects were made corresponding to changes in consumer surplus measures from Equation 19 (disaggregate demand mode), Equation 20 (trapezoid, all modes), and Equation 22 (trapezoid, automobile-drive-alone mode only); each change in consumer surplus computation was netted of tax payments (transfers) to obtain the true social welfare change.

A separate value-of-time computation was not made because in these scenarios Equation 22 is equivalent to Equation 20.

The results, given in Table 1, show that approximation errors range from 3 to 22 percent. As could be expected, the compounded error of using a linear approximation and considering only one modal effect is greater than the error associated with the linear approximation alone. Unfortunately, little in the way of a systematic bias can be inferred from the results except to note that the trapezoid measures of user cost impacts are higher than the disaggregate probability choice model estimates of change in consumer surplus.

The second set of tests are combinations of the automobile pricing strategies with transit improvements in the Boston North Shore area. All transit improvements involve express bus line-haul service to the downtown on exclusive lanes on major highway radial arteries. Consequently, automobile level of service for commuters who use these arteries is degraded because of lower peak-hour speeds. Four separate feeder options to the express bus were modeled: The express bus itself circulates on a fixed route in the service area; a subscription check-point minibus transfers patrons to the express bus; a subscription van with doorstep pickup and delivery also transfers patrons to the express bus; and a shared-ride taxi system on subscription performs the feeder function to express buses. The level of service of these various transit alternatives was determined from process models applied on a community-by-community basis as described by Dunbar and Kuzmyak (13).

The results of these tests, which are given in Table 2, indicate the potential for substantial error. Although the estimated percentage differences among alternative computations in Table 2 are somewhat smaller than those in Table 1, the absolute differences are an order of magnitude larger. This indicates that approximation errors tend to accumulate rather than cancel as the number of transportation attributes and modes affected by a policy increases. Another interesting result is that all trapezoid approximations are less than the exact probability choice computations; however, there appears to be little else that is systematic about the errors.

The simulation experiments reported above give somewhat equivocal results. It can be claimed, with justification, that errors on the order of 5-10 percent are insubstantial in comparison with errors in data and demand model specification. Therefore, the trapezoidal approximation may be adequate in the absence of a fully specified model. Another conclusion is that model specification errors (Equation 21) are of much greater magnitude than linear approximation errors. In general, if using the probability choice models to compute changes in consumer surplus does not entail substantial extra computational effort and if the models appear to have a better specification in terms of number of alternatives and attributes, then they are the preferred alternative.

Figure 1. Trapezoidal approximation: hypothetical increase in inclusive cost causing decline in aggregate demand.

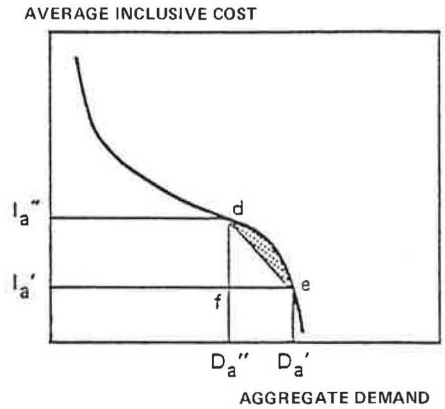

Table 1. Change in social welfare resulting from automobile pricing policies in Boston North Shore region.

Pricing Policy	Opportunity Cost for Work-Trip Commuters: Calculation from Disaggregate Model (Equation 19) ($/day)	Trapezoidal Approximations, All Modes (Equation 20): Calculation ($/day)	All Modes: Difference from Disaggregate-Model Calculations (%)	Automobile-Drive-Alone Mode Only (Equation 21): Calculation ($/day)	Automobile-Drive-Alone: Difference from Disaggregate-Model Calculations (%)	Total Transfer Payments ($/day)	Commuters in Region Affected by Policy (%)
$0.75 toll increase	1964	2019	3	2333	19	17 864	13
$1.00 parking surcharge	3001	3176	6	3214	7	16 071	22
75 percent gasoline charge	1140	1314	15	895	21	59 328	100

Table 2. Aggregate user costs resulting from automobile travel restraints and transit system improvements in Boston North Shore region.

Restricted Highway Lane for Express Bus Plus: Bus Feeder	Automobile Tax	Change in Consumer Surplus for Work-Trip Commuters ($/day): Calculation from Disaggregate Model (Equation 19)	Trapezoidal Approximation (Equation 20)	Difference (%)
Express bus	None	16 198	16 115	0.51
	$0.75 toll increase	33 526	31 276	6.71
	$1.50 parking surcharge	34 015	32 630	4.07
Shared-ride taxi	None	37 477	35 622	4.95
	$0.75 toll increase	54 923	48 516	11.67
	$1.50 parking surcharge	55 982	53 450	4.52
Van	None	30 690	28 700	6.48
	$0.75 toll increase	47 811	40 365	15.57
	$1.50 parking surcharge	48 351	45 487	5.92
Minibus	None	49 550	47 821	3.49
	$0.75 toll increase	67 619	62 422	7.69
	$1.50 parking surcharge	69 141	66 690	3.54
Average				6.24

CONCLUSIONS

With the advent of probability choice models, cost-benefit analysis can become a more powerful tool for transportation policy evaluation. The major problems with cost-benefit analysis are not so much conceptual as practical. The validity of the computation of changes in consumer surplus is dependent on the accuracy of demand models and the data used in the calculations. As probability choice models become more accurate representations of travel behavior, cost-benefit measures derived from these models become more relevant for policy decisions.

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Cost-Effectiveness Analysis: The Program of the Colorado Department of Highways

Art Ruth

The cost-effectiveness program developed by the Colorado Department of Highways is described. The program includes a computer model and a workbook that explains the computing procedures, input variables, and sources of input information. The computer and the workbook have enabled the department's district personnel to perform complex studies even though many of them have very little background in economic or benefit-cost analysis. The program is one of the first attempts to computerize the Stanford Research Institute methodology for analysis of transportation user benefits. The program quantifies the net present value-of-time, operating, accident, and maintenance benefits of highway project alternatives; compares benefits with required capital costs; and presents results in the form of first- and second-order benefit/cost ratios, net present values, and a verbal statement that indicates the most cost-effective alternative. The computer program also allows sensitivity analysis of selected variables.

Broadly speaking, cost-effectiveness analysis is the comparison of the benefits and the required capital costs of one action with those of another action. Usually, the no-action alternative is the basis on which certain build alternatives are judged to their economic advantage. Among the several measures used to quantify economic advantage, the most common are probably benefit/cost (B/C) ratio and net present value. The ratio is the division of benefits by capital costs, and the net present value is the subtraction of capital costs from benefits. For a certain build alternative to be considered economically justified over the no-action reference alternative, it must have a ratio greater than one or a positive net present value. If the ratio is less than one or there is a negative net present value, the no-action alternative is preferable from an economic standpoint. A ratio of one or a net present value of zero indicates an economic equality between the no-action and build alternatives.

With today's limited financial resources, cost-effectiveness analysis has become a major component in investment decisions in both the public and private sectors. Such analysis will become increasingly important in highway investment decisions because of the expected leveling off of revenues and a continuation of rapid price increases for construction materials and labor.

The Federal Highway Administration (FHWA) has begun to recognize the need to ensure cost effectiveness in highway project selection. This is indicated by the proposed FHWA regulation on urban highway and transit projects (1), which states the following:

> The policy in this regulation seeks to ensure that all federally funded major transportation investments for urbanized areas meet local and national goals and objectives in a cost-effective manner.... Every major urban transportation investment proposed for FHWA or Urban Mass Transportation Administration funding shall be supported by an analysis of relevant alternatives including a cost-effectiveness analysis.

In response to present and future needs for cost-effectiveness analysis, the Colorado Department of Highways has established the HYBENCO program. HYBENCO is an acronym for highway benefit cost. The program is composed of a computer model that performs cost-effectiveness calculations and a workbook manual that (a) defines the basic concepts and procedures involved in cost-effectiveness analysis, (b) describes in detail the calculations made by the computer program, (c) identifies necessary input data required to run the model and how or where data can be obtained and actually supplies some of the necessary input information, and (d) provides the operating instructions for the computer program.

PROGRAM DESCRIPTION

The HYBENCO computer model was based on information and analysis completed by the Stanford Research Institute (SRI) (2). The approach emphasized by SRI was a series of nomographs that allowed the analyst to estimate the road-user costs produced by various alternatives. Comparisons could then be made with capital costs to determine the most cost-effective alternative. Unfortunately, nomographs are inefficient when one is dealing with large projects and/or many alternatives. Individual calculations are time-consuming, and the errors inherent in reading nomographs are compounded to a potentially significant degree. Because of the deficiency of this approach in cases in which many calculations are required, the Colorado Department of Highways relied on an alternate SRI approach—the use of a series of cost tables that identified the specific road-user-cost factors. This approach normally required the analyst to perform a number of individual calculations to estimate total road-user costs, but computerizing these calculations made relying on the cost tables time-efficient, even with large projects, with an acceptable level of error.

Figure 1 shows a flow chart of the steps by which the HYBENCO program performs cost-effectiveness analysis. As seen, reductions in road-user and maintenance costs from the no-action alternative are the benefits of the build alternatives. Annual benefits for selected years are converted into a present-value "lump sum" by using a specified analysis period and discount rate. The HYBENCO program allows the analyst to input several discount rates for sensitivity analysis. Present-value road-user benefits of the build alternatives are compared with their respective net capital costs. Net capital costs are calculated by subtracting the investment costs of the no-action alternative from the capital costs of each build project option. The capital costs included in the program are right-of-way, relocation, and construction costs.

The HYBENCO model produces three output forms that allow the analyst to determine which alternative is most cost effective: (a) B/C ratios, (b) net present values, and (c) a written indication of which alternative is most cost effective. The model makes comparisons between the build alternatives and the no-action option and also makes comparisons among the build alternatives. Figure 2 shows an example of the computer output.

As mentioned, the benefit calculations made by the HYBENCO model are limited to reductions in road-user and maintenance costs. The road-user costs included in the computer model are time, operating, and accident costs. Four separate types of time costs can be calculated by the model, including time costs for traveling under smooth-flow conditions and additional time costs produced by speed changes and those accumulated while stopping or idling.

Operating costs are separated into four subcost categories: operating costs generated under smooth, level, and straight road conditions; operating costs for positive and negative grades; additional operating costs produced by curves; and operating costs that stem from idling, stopping, and changing speeds. The program also calculates subcategories of accident costs. These costs are for fatality, injury, and property-damage accidents.

The HYBENCO computer can calculate time, operating, and accident costs for the following five vehicle classes (1 kN = 224.8 lbf):

Class	Type
1	Automobiles, pickup trucks, and light delivery trucks
2	Single-unit, 53-kN trucks
3	Combination or 3-S2 diesel trucks
4	Automobiles with trailers
5	Composite, representing vehicles in classes 1-3

Figure 3 shows the input variables required to run the HYBENCO computer program. Line 1 indicates whether a batch-mode or teletype method of input will be used. Lines 2 through 5 include information on discount rates and default values for idling, time, and accident cost factors. Line 5 also indicates the period of analysis (horizon time) so that present-worth calculations can be made. Idling and time cost factors are inputted by vehicle type, whereas accident cost factors are inputted by fatality, injury, and property-damage accident types. All data in lines 1 through 5 are input once and remain the same for all alternatives.

Line 6 is intended for information on roadway segments. Capital and maintenance costs can be entered by segment, or the entire amount for each alternative can be entered into the first roadway segment. "Year one ADT" is defined as the average daily traffic (ADT) for the first year the project alternative is in operation. "Year X ADT" is defined as the average daily traffic for the future design year. "Year X number" is the number of years between year one and year X.

Line 7 is limited to vehicle information, including (a) average running speeds during the year X period; (b) the number of stops and idling times attributable to signals, stop signs, and railroad crossings; (c) speed-change cycles; and (d) operational cost factors. Additional times for speed changes and stops are also in-

Figure 1. Process of cost-effectiveness analysis in HYBENCO program.

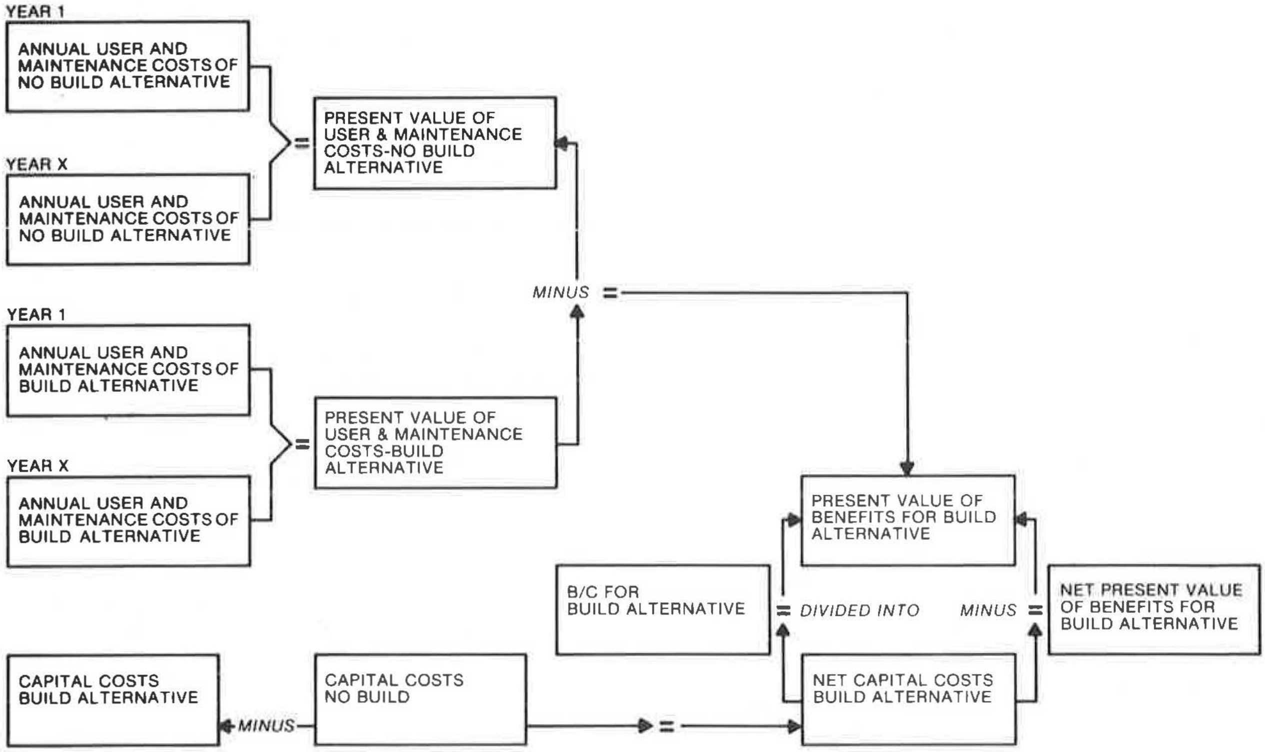


Figure 2. HYBENCO output. PROJECT ID: SH 83 VESTCHARGE RATE: 7 PERCENT 03/27/78 PAGE 8

COMPARISON OF ALTERNATIVES

NET PRESENT VALUES (THOUSANDS)

	USER, MAINTENANCE, AND AUTO TIME COSTS	CAPITAL COSTS	NET BENEFITS	B/C RATIO
1 vs 0	44000	40000	4000	1.100
2 vs 0	36000	30000	6000	1.200
2 vs 1	8000	10000	-2000	0.800

ALTERNATE 1 MOST ECONOMICAL

putted in line 7. Line 7 information is inputted for each vehicle type.

ADVANTAGES AND DISADVANTAGES OF HYBENCO

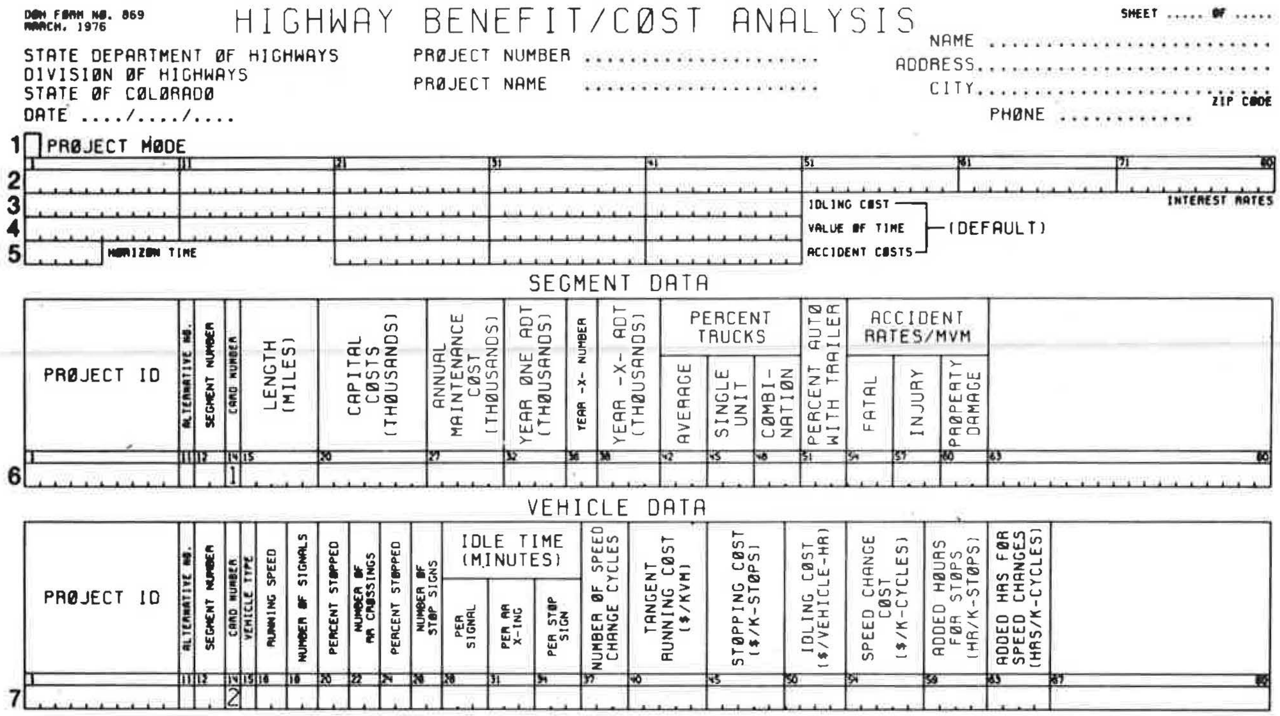
The HYBENCO computer program can perform a relatively precise road-user analysis with reasonable input demands. The program is flexible enough to allow the exclusion of some input variables that are expected to be frequently insignificant, such as idling and stopping costs. Particular vehicle classes can also be excluded. The HYBENCO program has been successfully transferred to Colorado Department of Highways district offices, where cost-effectiveness analysis is performed by persons who have little knowledge of economics or computers.

Another advantage is that the program can be used for a wide range of projects, from interchange to railroad-separation alternatives. The HYBENCO computer program also identifies the most cost-effective alternative in a verbal form that is easily understood by those who are not familiar with cost-effectiveness measures.

Finally, the computer model can be run by remote terminal as well as by batch. The availability of access by remote terminal allows the department's district offices around the state to directly input data and receive results without going through the central office.

The principal disadvantage of the HYBENCO computer program is that it requires the analyst to draw cost factors from tables contained in the manual. The program also requires the user to estimate additional time for idling and for stops. A further disadvantage is that the model is limited to a road-user analysis. Other economic, social, and environmental costs and benefits are not included in the cost-effectiveness analysis. However, the appropriateness of including these considerations in a single numerical measure is questioned. Not all economic, environmental, and social costs and benefits can be quantified. Thus, decisions cannot be based on any single measure. Unfortunately, cost-effectiveness measures are frequently assumed to be all-inclusive when they lump various types of impacts into a single number. When specific impacts are analyzed separately, whether in quantitative form or not, the danger of misinterpreting the results is lessened.

Figure 3. Input variables for HYBENCO program.



REFINEMENT OF THE PROGRAM

The Colorado Department of Highways plans to include the factor cost tables in the HYBENCO computer program. In addition, calculations of additional time for stopping and idling will be performed by the HYBENCO model. The final revision in the model will eliminate vehicle speed input. Instead, the HYBENCO program will calculate necessary speeds, given information on vehicle type, degree of curvature, grade, and ratio of volume to capacity. These changes will substantially simplify the present program.

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Benefit-Cost Analysis Based on the 1977 AASHTO Procedures

Douglas S. McLeod and Richard E. Adair

The benefit-cost analysis performed for FL-426A, a new highway facility in Florida, is described. The analysis was completed in general accordance with the American Association of State Highway and Transportation Officials (AASHTO) publication, A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements. The project, the analysis procedures, deviations from the AASHTO methodology, the analysis results, and suggested improvements to the AASHTO procedures are examined. A network approach was used for the benefit-cost analysis of this new facility, which has partial access control. A summary of the analysis appeared in the project's 1978 final negative declaration, an environmental impact document. Thus, it was one of the first benefit-cost analyses modeled after AASHTO procedures to appear in an environmental impact document approved by the Federal Highway Administration. It is concluded that, although the AASHTO procedures need to be computerized and their results are subject to wide variability among users, they are useful in determining the economic desirability of major highway improvements.

This paper presents a case study of a benefit-cost analysis for a 6.9-km (4.3-mile) segment of FL-426A. The study is generally based on the American Association of State Highway and Transportation Officials (AASHTO) publication, A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements (1), hereafter referred to as the AASHTO manual. The purpose of the analysis, which was based on a "willingness-to-pay" approach that is consistent with the philosophy of the AASHTO manual, was to determine the economic desirability of the highway project by investigating whether its user benefits exceeded its implementation and maintenance costs. The results of the benefit-cost analysis appeared in a 1978 final negative declaration (2), an environmental impact document approved by the Federal Highway Administration (FHWA). It was thus one of the first benefit-cost analyses generally based on the procedures of the AASHTO manual to appear in an FHWA-approved environmental impact document.

This paper describes the highway project, the analysis procedures, deviations from the methodology of the AASHTO manual, the analysis results, and suggested improvements to the manual's procedures. In part, this paper is intended to meet one of the urgent further research needs identified by the manual—the need for a state transportation agency to apply, test, and refine the procedures through actual use (1, p. 176).

PROJECT DESCRIPTION

FL-426A is a proposed four-lane, partial-control-of-access, major arterial route to be located in Orange and Seminole Counties (see Figure 1). This geographic area is the fastest-growing section of the Orlando standard metropolitan statistical area (SMSA), which in turn is one of the fastest-growing SMSAs in the nation. Based on projected traffic variations, the project study area was delimited by FL-438 to the south, US-441 (FL-500) to the west, FL-436 to the north, and I-4 (or FL-400) to the east (see Figure 2). In the environmental impact document, four alternative "build" corridors—A, A-1, B, and B-1—and the "no-build" concept were selected for study (Figure 2). All five alternatives were evaluated equally in the project's environmental impact document and benefit-cost analysis, but in the interest of brevity this case study concentrates on the analysis of the selected corridor—corridor A—and the no-build alternative.

The 2.9-km (1.8-mile) section of FL-426A from FL-431 to I-4 is scheduled for construction by the Florida Department of Transportation (DOT) during FY 1980/81. The 4-km (2.5-mile) section from US-441 to FL-431 and interchanges at US-441 and FL-431 are not scheduled for construction until after 1985.

ANALYSIS PROCEDURES

The methodology recommended in the AASHTO manual consists of eight major steps (1, p. 11):

1. Update of user cost factors,
2. Selection of the discount rate and other economic features,
3. Description of project characteristics and estimation of project costs,
4. Calculation of unit user costs,
5. Calculation of user benefits,
6. Conversion of user benefits to annual user benefits,
7. Estimation of residual value, and
8. Determination of present values and the economic desirability of the project.

Because of variations in the availability of data and the interrelationship of the analysis steps, the FL-426A benefit-cost analysis did not proceed in the exact order given above. For instance, much of step 3 and the first part of step 2 (selecting the discount rate) preceded step 1. These variations, however, were not significant and did not change the analysis results. For ease of understanding, the analysis steps are presented here as if they exactly followed the order given in the AASHTO manual.

Update of User Cost Factors

The AASHTO manual's base values for user cost were established in January 1975. The latest price levels available at the time of the analysis were for October 1976 (3). By using the manual's updating procedure (1, p.124), the appropriate value-of-time multiplier was determined to be 1.110. The running-cost multiplier was obtained from the manual's composite updating formula (1, p. 137), and the resulting multiplier was 1.134. It was not necessary to update accident costs and discomfort and inconvenience costs.

Selection of Economic Features

Instead of using a 4-5 percent discount rate as recommended by the AASHTO manual (1, p. 15), the Florida DOT uses a 7 percent discount rate. The 7 percent rate was chosen primarily because of its perceived validity and its greater acceptability to outside reviewers.

Unit values of time and vehicle running values, accident values, and discomfort and inconvenience values were determined next. The January 1975 base value of time used for passenger cars was \$3/vehicle-h. When updated by the 1.110 value-of-time multiplier, the October 1976 unit value of time became \$3.33/vehicle-h. Running costs were updated by using the 1.134 running-cost multiplier. National Safety Council (NSC) 1976 accident cost values of \$125 000/fatality, \$4700/nonfatal disabling injury, and \$700/property damage accident (4) were used. In urban settings, the 1976 Florida DOT discomfort and inconvenience values based on roadway operating conditions were \$0/vehicle-h for levels of service A, B, and C, \$0.10/vehicle-h for level of service D, \$0.25/vehicle-h for level of service E, and \$0.50/vehicle-h for level of service F. There is considerable debate concerning the values to be used in benefit-cost analyses for travel time, accidents, and discomfort and inconvenience, the last being the least recognized as a valid input. Although much of the benefit-cost literature does not support a willingness-to-pay approach, the AASHTO manual recommends its use (1, p. 154), and the Florida DOT believes it to be the best approach in evaluating road-user benefits against highway costs. Values of travel time are well documented, but the appropriate value to be used for this project was not certain. Since the 1975 travel-time value of \$3/vehicle-h is acceptable to Florida DOT decision makers, it was used as a base value. NSC accident values are in widespread use throughout the United States and, more specifically, are used throughout the Florida DOT in safety decision making. The use of discomfort and inconvenience values based on roadway operating conditions is accepted by the Florida DOT.

A 20-year analysis period was chosen: 1980-2000. A 20-year analysis period is typically used by the Florida DOT to evaluate major highway projects. Because the Orlando Urban Area Transportation Study was under FHWA "conditionally certified" status at the time of this benefit-cost analysis, a special process had to be undertaken to obtain acceptable traffic projections through the year 2000. In order to use the 20-year analysis period and for purposes of simplicity, it was assumed that construction of the whole project would be completed by 1980 (as stated earlier, none of the project will actually be completed by 1980 and much of it will not be completed anywhere near that date). The same analysis period and assumed construction completion date were also used in all other impact analyses within the environmental impact document. The study years actually used were 1981 and 2000; however, costs were converted to 1978 dollars.

Description of Project Characteristics and Estimation of Costs

Road segments in the highway network that were affected by the selection of an alternative were selected on the basis of changes in their average annual daily traffic (AADT) or average daily traffic (ADT) for a given year. Each of the four alternative corridors had 29 affected road segments, which constituted the highway network. The no-build concept consisted of 23 road segments within its network. As stated above, AADT levels were obtained from the Orlando Urban Area Transportation Study. Because of variations in the study's computer-run traffic assignments, AADT levels were adjusted as warranted to balance traffic assignments. Traffic parameters, such as the percentage of AADT that consists of trucks, were also obtained. Daily roadway capacities were derived from the 1965 Highway Capacity Manual (5). For an example, see Figure 3, which shows the year 2000 ADT levels and daily capacities of the network roads

Figure 1. Location of FL-426A project area.

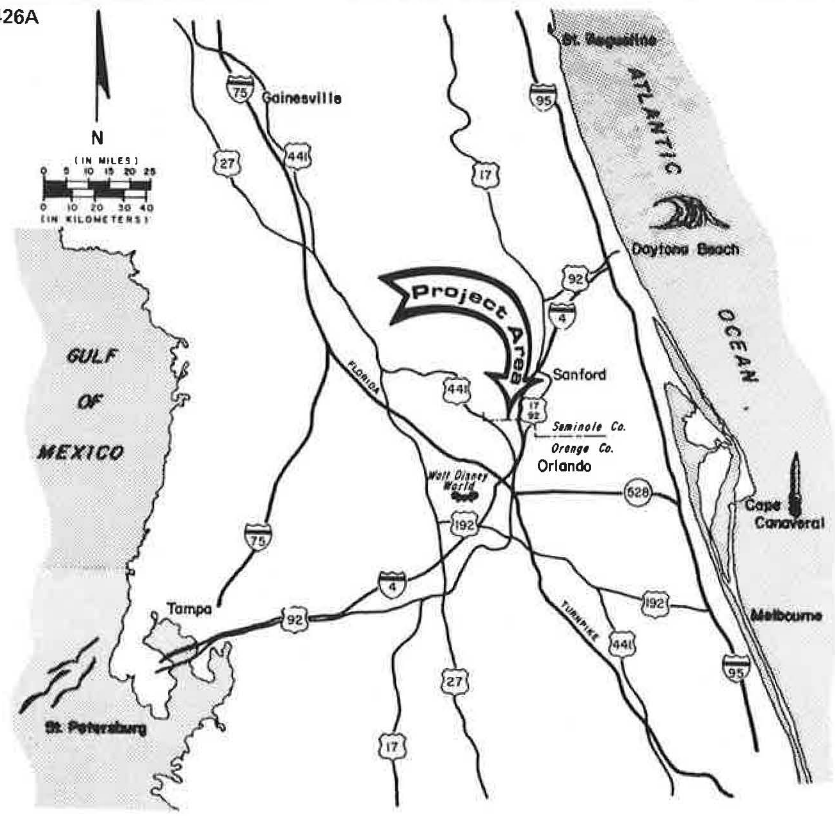

Figure 2. Alternative corridors.

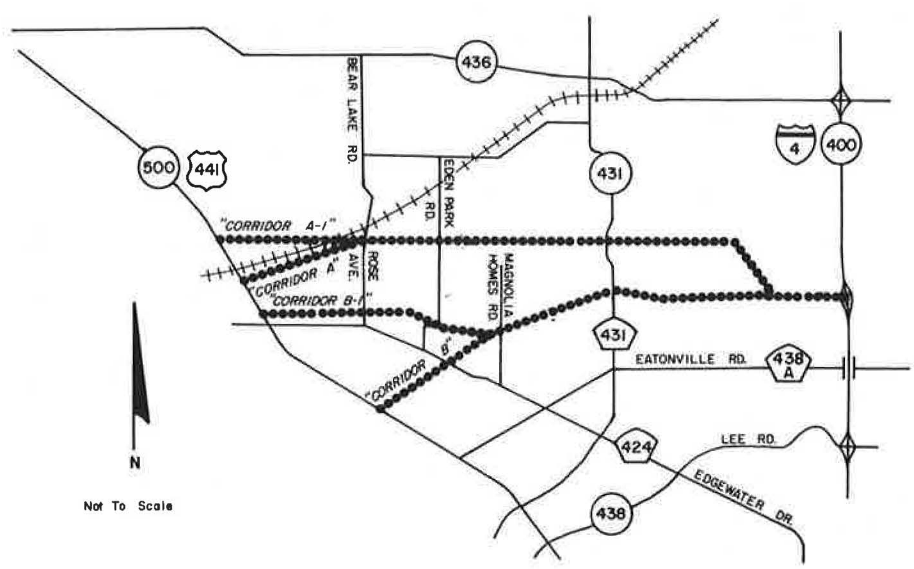

Figure 3. Year 2000 ADT levels and daily capacities of roads affected by corridor A.

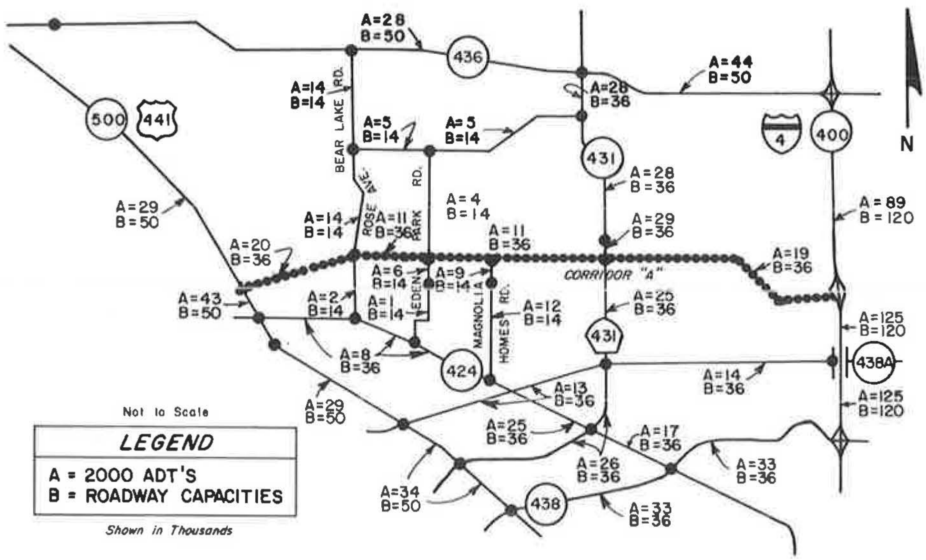

Table 1. Net highway cost information for corridor A.

Highway Cost Classification	Year(s) Costs to Be Incurred	Present Worth Factor for Single Amount	Net 1978 Cost Estimate ($)	1978 Net Present Worth Cost ($)
Preliminary engineering	1978	1.0	134 000	134 000
Right-of-way	1980	0.8734	1 781 000	1 556 000
Construction	1980	0.8734	5 880 000	5 136 000
Maintenance	1981-2000	8.6479[a]	27 850	241 000
Total				7 067 000

[a]Uniform series present worth factor (10.594) times single-amount present worth factor (0.8163).

affected by corridor A implementation.

Four highway cost classifications were used: preliminary engineering, right-of-way, construction, and maintenance. The highway cost classifications given in the AASHTO manual (1, p. 37)—advance planning, preliminary engineering, and final design—were grouped together as "preliminary engineering". Operational costs were considered insignificant. Net highway cost information for corridor A is given in Table 1.

Calculation of Unit User Costs

Daily and two-way traffic volumes were used throughout the analysis to calculate basic section costs. Average running speeds were computed by using Florida DOT equations developed in the Fifth District and derived from the Highway Capacity Manual. Road surfaces were assumed to be level, and additional running costs attributable to curves were considered insignificant. Travel time, level tangent running costs, and speed-change costs for all network road segments were calculated by using the basic-section-cost nomographs given in the AASHTO manual (1, pp. 50-62). Basic section costs were also adjusted to account for the truck mix in the traffic stream by using conversion factors (1, p. 42).

Historical accident and severity rates were obtained for all of the affected network roads for which the Florida DOT had accident data. It was assumed that the remaining roads had the same accident rates as state primary roads with similar design and location characteristics. For all roads projected to be upgraded during the 20-year analysis period, accident rates were lowered by 10 percent to reflect adherence to the latest design standards. Accident cost values per 1000 vehicle miles were then calculated for all affected network road segments (since this analysis was based on U.S. customary units of distance, no SI equivalents are given).

For simplicity and to make the network analysis manageable, section transition and intersection delay costs were not considered. Level of service F traffic conditions were handled in a general way by redistributing excess traffic demand over parallel routes. Bus user costs were considered insignificant.

Calculation of User Benefits and Conversion to Annual Benefits

Daily network user costs for the five alternatives were calculated and then converted to yearly costs for the years 1981 and 2000. An excerpt from the worksheet used in the analysis for Corridor A year 2000 user costs is shown in Figure 4. Subsequent calculations of user benefits are addressed in the final step of the process.

Estimation of Residual Value

Estimating residual value is the next step in the AASHTO manual methodology. However, the Florida DOT excludes it from consideration in its analyses. The Florida DOT decision was based on the relatively small residual values obtained and the desire to simplify benefit-cost analyses.

Determination of Present Values and Economic Desirability of Project

User costs for the 20-year analysis period for each alternative were calculated by using the present worth factor (1, p. 31). Each respective corridor's user costs were then subtracted from the no-build user costs to determine user benefits for each corridor, as given below:

Corridor	User Benefits ($)
A	23 579 000
A-1	18 005 000
B	8 355 000
B-1	14 255 000

Then the net present values for the four alternative corridors were computed by subtracting the respective net highway costs from the user benefits. These results are given below:

Corridor	Net Present Value ($)	Benefit/Cost Ratio
A	16 512 000	$23 579 000 ÷ $7 067 000 = 3.3
A-1	10 313 000	$18 005 000 ÷ $7 692 000 = 2.3
B	580 000	$8 355 000 ÷ $7 775 000 = 1.1
B-1	7 190 000	$14 255 000 ÷ $7 065 000 = 2.0

It can be seen above that corridor A had the greatest net present value. The Florida DOT uses benefit-cost ratio instead of net present value for benefit-cost-analysis presentations primarily because the lay person is more familiar with the former. As the table above shows, corridor A also had the greatest benefit-cost ratio. Thus, by either method, corridor A was the most economically desirable alternative.

PROJECT RESULTS

As stated above, corridor A had the greatest economic desirability of the build alternatives. It was also the corridor alternative selected for implementation. The environmental impact document for the project stressed that a benefit-cost analysis that involved only road user benefits and highway costs was merely one criterion in the approval of a project alternative. Strangely, for a new major highway route, corridors A and A-1 had only minimal adverse nonuser economic, social, and environmental effects. In fact, community and environmental interests endorsed corridor A or A-1. Thus, since virtually all factors pointed to the approval of one of the A corridors over one of the B corridors and the no-build alternative, the relative importance of the benefit-cost analysis in the overall decision-making process or in the choice of one of the A corridors is hard to determine. However, the benefit-cost analysis did play a significant role in the process of selecting either corridor A or A-1. Since the nonuser economic, social, and environmental impacts of the two corridors were generally the same, the only major factors left for evaluation were road user benefits and highway costs. Both of these factors, as well as the combination of the two, clearly indicated a preference for corridor A. It is difficult to determine whether the decision to implement corridor A was primarily a result of the benefit-cost analysis as a whole or whether one of its two major components had a greater influence. Nevertheless, the benefit-cost analysis did clearly point to the desirability of corridor A over corridor A-1 and provided a sound economic and engineering justification for the decision.

Figure 4. Portion of worksheet for corridor A year 2000 user costs.

Road Segment (1)	Travel Time (h/1000 vehicle miles) (2)	Updated Value of Travel Time/1000 Vehicle Miles (column 2 x $3.33/h) (3)	Value of Discomfort and Inconvenience/1000 Vehicle Miles (column 2 x level-of-service values) (4)	Updated Tangent Running Cost/1000 Vehicle Miles (5)	Updated Speed-Change Running Cost/1000 Vehicle Miles (6)	Accident Costs/1000 Vehicle Miles (7)	Time and Running Cost/1000 Vehicle Miles (columns 3 + 5 + 6) (8)	Adjusted Vehicle-Mix Time and Running Cost/1000 Vehicle Miles (column 8 x vehicle-mix factors) (9)	Road Segment User Cost/1000 Vehicle Miles (columns 4 + 7 + 9) (10)	Road Segment Length (miles) (11)	Road Segment User Cost/1000 Vehicle Miles (columns 10 x 11) (12)	ADT (thousands of vehicles) (13)	Annual Road Segment User Costs (columns 12 x 13 x 365 days) (14)
1	33.0	$109.89	$ 3.30	$79.38	$5.99	$38.52	$195.26	$206.39	$248.21	1.90	$471.60	43.8	$ 7,539,000
2	27.0	$ 89.91	$ 0.00	$80.51	$3.74	$38.52	$174.16	$184.09	$222.61	3.95	$879.31	27.6	$ 8,858,000
3	21.5	$ 71.60	$ 0.00	$83.92	$5.04	$ 3.62	$160.56	$170.19	$173.81	2.25	$391.07	89.0	$12,704,000
4	37.0	$123.21	$18.50	$78.81	$15.65	$ 3.62	$217.67	$230.73	$252.85	1.80	$455.13	124.7	$20,715,000
5	37.0	$123.21	$ 9.25	$78.81	$6.33	$25.87	$208.35	$220.23	$255.35	1.80	$459.63	33.4	$ 5,603,000
...	...	...	...	...	...	...	...	...	...	...	...	...	...
25	25.5	$ 84.92	$ 2.55	$80.51	$5.78	$21.79	$171.21	$180.97	$205.31	0.60	$123.19	42.5	$ 1,911,000
26	21.5	$ 71.60	$ 0.00	$83.92	$4.01	$21.79	$159.53	$166.62	$188.41	1.40	$263.77	29.4	$ 2,831,000
27	22.0	$ 73.26	$ 0.00	$82.78	$4.55	$21.79	$160.59	$169.74	$191.53	1.40	$268.14	33.6	$ 3,288,000
28	22.0	$ 73.26	$ 0.00	$82.78	$2.11	$23.42	$158.15	$167.16	$190.58	1.70	$323.99	11.2	$ 1,324,000
29	25.5	$ 84.92	$ 0.00	$80.51	$3.74	$23.42	$169.17	$178.81	$202.23	0.70	$141.56	19.8	$ 1,023,000
									TOTAL NETWORK USER COSTS			=	$96,398,000

SENSITIVITY ANALYSIS OF INPUT DATA

In the project benefit-cost analysis, the user cost components were not isolated and a sensitivity analysis of the input data was not conducted. This was not done at the time of the analysis primarily because of the additional computational time required. However, the Florida DOT has recently computerized much of the AASHTO manual's methodology, which makes it possible to separate the user cost components and to perform sensitivity analyses with ease (6). Computerized results for the no-build alternative and corridor A user costs obtained by using the input data described in this paper are given in Table 2. The table indicates that savings in travel time produced the greatest proportion of benefits, followed by savings in vehicle running, discomfort and inconvenience, and accident costs. It should be noted that the total corridor A benefits from the computerized model ($22 236 000) varied by approximately 6 percent from the hand-calculated value ($23 579 000).

Corridor A net present values, which are a result of variations in the various input data, are given in Table 3. As the table indicates, net present values for corridor A are positive for every variation in the sensitivity analysis. Thus, for all the variations analyzed, implementation of corridor A is economically desirable.

EVALUATION OF AASHTO MANUAL METHODOLOGY

The AASHTO manual can assist economic analysts in evaluating the economic benefits and costs of highway projects that affect a highway network. However, two major drawbacks limit its effectiveness: the amount of hand calculations required to perform analyses and the probable numerical inconsistency of the results obtained by different analysts.

For the FL-426A benefit-cost analysis, a minimum of 10 000 hand calculations were done. At least 75 percent of the calculations were recalculations as a result of changes in input data, computational errors, and routine checks. Even with substantial review and checking of calculations, the FL-426A benefit-cost analysis was not free of errors. Fortunately, none of the errors discovered since the approval of corridor A would substantially alter the basic conclusion that implementation of corridor A would be economically desirable. Nevertheless, the usefulness and accuracy of the AASHTO manual methodology are lessened because of its reliance on a great number of hand calculations. The need to computerize the methodology to handle routine calculations is important and is recognized in the manual (1, p. 176). The Florida DOT has begun that task and has reached the point where all the analysis procedures used on the FL-426A project are incorporated into a computer program.

The second limitation of the AASHTO manual is the wide variability in results when different economic analysts use the methodology. Although the manual provides useful examples to illustrate various aspects of the methodology, it provides no specific guidelines for the various types of projects, and the examples are replete with simplifying assumptions. Specifically, although the manual gives an example of network effects analysis (1, p. 89), it does not provide guidelines for which simplifying assumptions are and are not desirable. Thus, by implication, the AASHTO manual allows the economic analyst great flexibility in selecting what the analyst feels are the most appropriate factors to be considered in analysis of a project. However, because the economic analyst is allowed this flexibility, considerable variations in numerical results will occur among analysts, especially as projects increase in size and scope.

It is recognized that benefit-cost analyses are not as exact as most other engineering analyses and that a step-by-step procedure to cover all situations is not practical or even desirable. The analyst must be given some flexibility in determining the appropriateness of inputs in benefit-cost studies. Nevertheless, the guidelines provided in the AASHTO manual appear to be too broad to generate reasonable uniformity of results. More specific guidelines for each type of project should be provided.

On major highway projects, the Florida DOT has provided and is continuing to provide its employees more definitive guidelines. Most of these guidelines follow the procedures of the AASHTO manual; however, as this paper has shown, some procedures are simplifications and others are not in accordance with those given in the manual.

Aside from the input values and simplifications pre-

Table 2. User costs for no-build alternative and corridor A and resulting corridor A benefits.

User Cost Component	User Costs ($)		Corridor A User Benefits	
	No-Build	Corridor A	Amount ($)	Percent
Travel time	291 153 000	277 862 000	13 291 000	59.8
Vehicle running	294 692 000	290 266 000	4 426 000	19.9
Discomfort and inconvenience	6 731 000	3 974 000	2 757 000	12.4
Accidents	62 262 000	60 500 000	1 762 000	7.9
Total	654 838 000	632 602 000	22 236 000	100.0

Table 3. Sensitivity analysis of major input values and resulting effects on net present value of corridor A.

Case	Discount Rate (%)	Travel Time Value ($/h)	Discomfort and Inconvenience Value[a] ($)	Accident Values[b]	1978 Present Worth of Residual Value ($)	Corridor A Net Present Value ($)
1	7	3.33	0.00-0.50	NSC	0	15 170 000
2	4	3.33	0.00-0.50	NSC	0	22 711 000
3	10	3.33	0.00-0.50	NSC	0	10 043 000
4	7	1.11	0.00-0.50	NSC	0	6 309 000
5	7	0.00	0.00-0.50	NSC	0	1 879 000
6	7	3.33	0.00	NSC	0	12 413 000
7	7	3.33	0.00-0.50	Manual	0	14 220 000
8	7	3.33	0.00-0.50	0	0	13 408 000
9	7	3.33	0.00-0.50	NSC	503 000	15 673 000

[a] Discomfort and inconvenience values are $0.00/vehicle-h for levels of service A, B, and C; $0.10/vehicle-h for level of service D; $0.25/vehicle-h for level of service E; and $0.50/vehicle-h for level of service F.

[b] NSC accident values are given earlier in this paper. Manual values are for road segments in a suburban location (1, p. 67).

viously referred to in this paper, with which we generally concur, we offer two other suggestions as a result of the FL-426A analysis:

1. The nomographs [primarily on pages 50-61 (1)] are too small to obtain reasonably accurate values. If benefit-cost analyses are conducted by hand, the nomographs should be enlarged significantly.

2. The calculation of a present worth factor for a stream of benefits (1, p. 31) should perhaps be changed to a present worth factor for a stream of costs involving a specific user cost component. For instance, when the sensitivity analysis for value of travel time for the FL-426A project was initially conducted, it was noted that changing that value changed the other user benefits as well as the total benefit over the 20-year study period. This occurred because the benefit received from reduced travel time did not grow at the same rate as the total user benefits and the recommended present-worth-factor formula recommended in the AASHTO manual is based solely on total yearly user benefits. It should be noted, however, that the manual does caution the use of the factor, although not for the reason stated above (1, p. 32).

In conclusion, the Florida DOT feels that the AASHTO manual is useful in conducting highway network benefit-cost analyses. When the methodology is computerized and there is greater standardization of underlying assumptions, the manual will become a more useful tool for decision makers.

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Reducing Urban Blight: A Reconnaissance of Current Highway Experiences

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An exploratory study of highway improvements and the mitigation of adjacent urban blight in central business districts, undertaken as background for a more extensive study mandated by Congress in 1978, is described. Some 73 cities had undertaken or were undertaking a total of 80 highway-related projects to mitigate blight, but only material from 36 projects was complete enough to analyze further. The majority of the cited causes of blight stem from characteristics of the area where the highway is located rather than from characteristics of the highway itself. A wide variety of measures to overcome blight have been implemented or proposed, including (a) coordination of highway projects with urban renewal plans and the construction of community facilities, (b) construction of expressways and parking facilities, and (c) transportation system management measures, automobile-restricted zones, and construction of pedestrian or bicycle facilities. Specific cause-effect relations could not be determined, but causes of blight and associated mitigative measures are identified. The extensive use of highway projects in combination with urban renewal measures suggests that institutional and procedural problems are significant issues. The results of the preliminary analysis have provided a basis for a more detailed field analysis of eight case-study cities, which will be incorporated in a report to Congress that is due in November 1980.

On November 6, 1978, Congress passed the Surface Transportation Assistance Act of 1978. The law mandated the Secretary of Transportation to "conduct a study of the potential for reducing urban blight adjacent to federal-aid primary and Interstate highways located in central business districts." The Federal Highway Administration (FHWA) was given primary responsibility for conducting the study. Section 159 of the act describes the content of the study, which is to include the following:

1. Description of adverse effects on land adjacent to federal-aid primary and Interstate highways;
2. Description of mitigative measures;
3. Estimates of potential increases in the value of adjacent land;
4. Contribution to various aspects of urban life, such as employment or recreational opportunity; and
5. Financial proposals.

The report to Congress will be based on case studies now being conducted under contract. To provide a basis for selecting the case-study sites and to consolidate knowledge on the mitigation of urban blight near highways, FHWA has conducted through its field offices a reconnaissance of current experience that was deliberately limited to readily available information and published planning reports. This paper is based on the reports received as a result of the FHWA reconnaissance effort.

Most of the information available concerned the first two items required for the congressional report, and the analysis is limited to those two areas. The conclusions drawn are tentative and are expected to be further developed and crystallized by additional research. In the interim, this paper summarizes the current experiences of selected cities in dealing with the problem of urban blight adjacent to highways in central business districts (CBDs).

BACKGROUND

Congress first focused national attention on urban blight on July 10, 1892, when a study of the slums of Baltimore, Chicago, New York, and Philadelphia was prepared in compliance with a joint resolution to "show conditions of residents" (1). The study resulted in a descriptive analysis of slum residents and their living conditions: sex, place of birth, occupation, earnings, health, illiteracy, arrests, persons per dwelling unit, and number of saloons. Slums were found to contain "dirty back streets", house "a squalid and minimal population", and consist of "low and dangerous neighborhoods " (1).

On December 3, 1931, President Hoover convened the National Conference on Home Building and Home Ownership in Washington, D.C. The Committee on Blighted Areas and Slums addressed the issues of blight, including its cause and clearance. According to the committee (2), a blighted area—defined as an economic liability to its community—comes about as a result of zoning too large an area for commerce, overcrowding, the development of incompatible land uses, natural handicaps (such as swampy soil), the cost of mortgages exceeding the earning ability of the area, a rising standard of living, and central attitudes such as a belief in the desirability of suburban living.

The committee also recommended a plan for slum clearance under which local authorities and private enterprise would go into partnership. By using the police power of the state, localities would take the land, clear it of buildings, and sell it to a limited dividend company. Proper compensation would then be paid to displaced residents. The property would be sold to private developers solely for housing construction and rehousing the population (3).

On July 15, 1949, the Housing Act of 1949 was enacted. It established the national housing objective: to provide federal aid to assist programs in slum clearance and community development and redevelopment. This act was the first major federal legislation whose objective was to eliminate blight and strengthen the economy of cities. In the 25 years between 1949 and 1974, 1200 U.S. cities undertook federally financed renewal projects. In total, $12 billion in federal funds was committed in addition to state and local funds.

Since 1949, the program has undergone many changes. Until 1967, massive clearance and demolition were emphasized; after 1967, increased emphasis was placed on rehabilitation and preservation, funding was changed to an annual basis, and citizen participation was administratively required.

The past effectiveness of urban renewal was evaluated in a 15-month study undertaken by the Real Estate Research Corporation in 1975 for the U.S. Department of Housing and Urban Development (HUD). The study examined 70 urban renewal projects in 22 cities. The findings of the report (4) include the following:

1. By itself, an urban renewal program has relatively limited powers to enhance a city's economic development. Therefore, it cannot significantly counteract certain basic trends in society that undermine the strength of central-city economies or their competitive position relative to suburban shopping centers, industrial parks, and residential developments.
2. Urban renewal has significantly assisted CBDs in many cities to enhance their competitive strength in relation to outlying employment and retail centers. It has done this in a number of ways, including removing blight in or near the CBD, assembling sites for new development, persuading private developers to build near the CBD, and creating a more favorable investment climate.

In the past, concern about urban blight has focused on housing and residential elements. Only recently has this concern focused on transportation elements. Much is known about residential urban blight but little about blight adjacent to highways in CBDs. What are its causes? What is the incidence of its occurrence? What can be done about it? These and other issues are explored in this paper to obtain an overview of the subject of blight from the transportation perspective.

STUDY APPROACH

After discussions with the staffs of HUD and the Urban Mass Transportation Administration (UMTA), FHWA was able to identify (a) renewal projects in blighted CBDs and (b) highway projects designed to improve community conditions, such as joint use of right-of-way or air rights on federal-aid primary or Interstate highways. Preliminary discussions produced information on 29 projects. To estimate the potential for reducing urban blight, it was first necessary to know whether highway projects had indeed been used to reduce blight in a CBD. Unfortunately, no project provided information on both highways and urban blight. To establish a stronger foundation for the national study of urban blight, an exploratory study was needed to make such information available.

FHWA's regional and division offices were requested to provide supplemental information. The purposes of the additional information were to

1. Identify those cities where blight adjacent to highways exists,
2. Identify the nature of the problem,
3. Identify attempted or proposed solutions, and
4. Obtain sufficient information to select 8-10 cities for a more intensive research effort based on case-study sites.

This paper discusses the results obtained for the first three information items. These results may suggest directions for further research in the area of blight and highway transportation.

REQUEST FOR INFORMATION AND RESPONSE

On March 2, 1979, the FHWA headquarters office formally requested that the 10 regional FHWA offices "identify and briefly describe the status of existing, or planned, renewal areas which involve: (1) existing Interstate or Federal-aid primary highway rights-of-way, or air-rights, and (2) blighted areas in or abutting a CBD." "Readily available copies of plans for renewal projects" were also requested. Implicit in the request was the assumption that any serious effort to mitigate highway impacts in blighted areas had to be coordinated with ongoing renewal or redevelopment activities.

To assist the regional offices, 29 previously identified projects in 17 states were briefly described. These projects ranged from a North Birmingham, Alabama, community redevelopment project that consists of a public parking facility and a grade-separated bridge to a Seattle project that consists of a park over I-5. The regional offices were asked to focus first on these 29 areas and then to identify and describe other areas.

The FHWA regional and division offices supplied a large quantity of information on potential candidate projects. These ranged in scope from relocating a ramp to obtain more open space (Portland, Oregon) to a complex group of measures combining construction of an Interstate segment through the CBD with a pedestrian mall, new paving, lighting, utilities, traffic controls, and three new parking structures (St. Joseph, Missouri). More than 80 projects were recommended for possible inclusion in the study. All regions responded, although not all states contained suitable projects. Almost 40 percent of the projects lie in the northeastern states, which contain many stagnant, older cities.

The FHWA field offices gathered and sent to Washington a body of information for this study that ranged from letters to project reports. Of the 36 letters received, 15 contained substantive information on one or more projects. In addition, 55 reports on projects were received, including references to 29 other reports on the same projects. This large response was reviewed, and fact sheets were prepared on the 36 most relevant projects, which are listed in Table 1.

The 36 projects were then examined for six types of information required for the Section 159 study, including:

1. Description of adverse effects on adjacent land,
2. Description of mitigative measures,
3. Estimates of potential increases in the value of adjacent land,
4. Estimates of potential costs of highway improvements,
5. Contribution of mitigative measures to various aspects of urban life, and
6. Financial proposals.

Based on the information received, no project recommendation includes information on all of these areas. Eleven projects have some information on four or five of the areas, 6 projects have information on three areas, and 19 projects have information on two or fewer areas. Notwithstanding the different degrees of completeness, however, sufficient information is available to identify (a) cities that have blight adjacent to highways, (b) some aspects of the blight problem, and (c) some attempted or proposed solutions.

ANALYSIS

The preliminary information relevant to the first two areas emphasized by Section 159—adverse effects on adjacent land and mitigative measures—has been analyzed in detail. General decline of the CBD and traffic congestion were identified most frequently (eight times each) as the cause of blight in the areas of the projects. Lack of access to the CBD is closely related to these causes and was cited five times. The causes of blight were divided into area-related and highway-related causes. Most causes were area related and stemmed from characteristics of the area in which the highway is located, not from characteristics of the highway or the highway-related transit facility, as the table below indicates (note that projects may cite more than one cause):

Cause	Number of Projects
Highway-related	
Nonconformance of structure with aesthetic or urban design values (includes one transit station)	6
Highway-associated noise or air pollution	4
Space required for right-of-way	1
Subtotal	11
Area-related	
General decline of CBD	8
Traffic congestion on CBD streets	7
Lack of access to CBD	5
Incompatible land uses	4
Age of buildings	3
Lack of parking	1
Lack of community facilities	1
Subtotal	29
Total	40

This finding indicates that measures to mitigate the impacts of highways may be more effective when they are treated as elements of larger strategies to eliminate blight rather than as independent measures taken to change the impact of the highway on its surroundings. Experience with the urban renewal program of the 1960s also suggests that isolated measures have limited success in curtailing urban blight.

One such example is that of Lewiston, Maine, where a downtown revitalization project includes an element for street improvements (5). Little major public or private reinvestment in the CBD has occurred since the project was constructed in the early 1900s. Because of this lack of reinvestment, the CBD has slowly deteriorated. High traffic volumes on Lisbon Street, the city's main thoroughfare, have combined with a narrow right-of-way, many pedestrian crossings, and the canyon effect of tall buildings on air quality to exacerbate the blighting of the CBD.

In March 1978, Lewiston was awarded a HUD grant to rehabilitate various buildings, establish a loan pool for businesses, install elevators in multistory buildings to stimulate private rehabilitation, build a parking garage, and improve the water system. As part of the revitalization project, which began in 1978, the Lisbon Street sidewalks will be widened, two-thirds of the on-street parking will be shifted to a five-deck parking garage, and Main Street will be widened to absorb additional traffic. In addition to $3.2 million of HUD funds allocated to housing-related problems, there are proposals to use FHWA funds for street improvements, Economic Development Administration funds for operation and maintenance of the garage, Small Business Administration funds for loan guarantees to small businesses, and UMTA funds for bus shelters. Street improvements will encourage pedestrian movement and hamper downtown through traffic. In combination with other efforts, transportation improvements will result in a greater use of the Lewiston CBD, thereby encouraging its revitalization.

A wide variety of mitigative measures were cited for the 36 projects for which fact sheets were prepared:

Measure	Number of Projects
Highway-related	
Construction of expressway	13
Construction of parking facility	12
TSM measures	11
ARZ or transit mall	10
Construction of pedestrian or bicycle facilities	8

Measure	Number of Projects
Reclamation of land from transportation use	6
Construction of CBD arterials	6
Air rights and joint development	6
Demolition of highway	4
Construction of transit facility	2
Buffering adjacent land uses from expressway	2
Subtotal	80
Area-related	
Coordination with urban renewal plans	18
Coordination with construction of community facilities	17
Subtotal	35
Total	115

The description of a single project often contained several mitigative measures in combination. Mitigative measures were divided into area-related and highway-related measures. Area-related measures comprised coordination through planning of several measures in an area, including highway improvements, and were widely used. Highway- or transit-related measures involved direct changes in highways or other transportation facilities and, as a group, were more frequently used than area-related measures. Approximately 33 of the highway-related measures resulted in altering objectionable features of highways. These highway-related measures include transportation system management (TSM), automobile-restricted zones (ARZs) or transit malls (which appear to be relatively popular), reclamation of land, demolition of a highway, and buffering of adjacent land. The rest of the highway-related mitigative measures involve provision of new or different transportation facilities to mitigate blight. For example, in St. Joseph, Missouri, completion of I-229 is viewed as a measure that will mitigate the blighting influence of congestion on local streets in the CBD.

The Lechmere Canal and Triangle Area Development Project in Cambridge, Massachusetts, is an example of the application of a wide variety of mitigative measures (6). The area, which is currently composed of successful and marginal businesses and vacant buildings, is characterized by a declining tax base, a high level of unemployment, lack of open space and parking, and poor pedestrian connections to the riverfront area.

In 1978, Cambridge was awarded a $6.8 million grant from HUD for restoration and economic development of the East Lechmere riverfront area. Plans call for the beautification of Otis Street; restoration of an old courthouse into educational services, law offices, retail outlets, and restaurants; construction of a parking garage; and low-interest housing rehabilitation loans. These improvements are to be complemented by roadway improvements, financed for the most part by FHWA. Road improvements consist of widening Binney Street; partially closing Cambridge Parkway along the river; widening Commercial Avenue; constructing a new, widened bridge over the Lechmere Canal; and upgrading the intersection at Commercial Avenue and Monsignor O'Brien Highway. As a result of these improvements, (a) more park land will be developed; (b) the river will be more accessible to pedestrians, bicyclists, and families; and (c) traffic congestion will be relieved. Urban system funds totaling $3.6 million will finance these highway improvements. Finally, the present elevated Lechmere Station, which crosses a parkway road and causes confusion, traffic congestion, and blight in one of the city's busiest intersections, will

Table 1. Projects selected for inclusion in FHWA study of urban blight.

Federal Region	State	City	Project
1 and 2	Connecticut	Hartford	Walk system in downtown[a]
	Maine	Lewiston	Elimination of parking and other improvements to Lisbon Street
	Massachusetts	Boston	Central artery reconstruction (I-93)
		Cambridge	Lechmere Square redevelopment; reconstruction of street and waterfront park[a]
		Medford	Redevelopment of MBTA station; reconstruction of streets
	New Jersey	Camden	I-76 and I-676 joint development with HUD[a]
	New York	Buffalo	Buffalo pedestrian mall over NY-5
		Elmira	North-south arterial through CBD
		Poughkeepsie	East-west arterial through CBD renewal
3	District of Columbia	Washington	I-95 center leg, inner loop
		Washington	Potomac River freeway in replacement of Whitehurst Freeway
	Maryland	Baltimore	City Boulevard opportunity for joint development
	Virginia	Norfolk	I-464, I-264 renovation of Berkely community[a]
	West Virginia	Charleston	I-64, I-77 construction in urban renewal area[a]
4	Florida	Pensacola	I-110 multiple-use project
	Kentucky	Louisville	Variety of TSM projects in CBD
5	Michigan	Detroit	Street improvements in support of Cadillac Square Mall project in CBD[a]
	Minnesota	Duluth	Metro retail center over I-35
	Wisconsin	Madison	Pedestrian mall in CBD (Federal-Aid Urban System)[a]
6	Louisiana	Alexandria	Construction of I-49 and renewal in CBD[a]
		New Orleans	I-10 multiple-use construction in CBD
	New Mexico	Albuquerque	Formation of one-way couplet in CBD[a]
	Texas	Laredo	I-35 and renewal construction in CBD
		San Antonio	Double decking of Vista Verde Interstate
7	Iowa	Dubuque	East-west expressway through downtown
		Waterloo	I-380 and downtown construction
	Missouri	St. Joseph	I-229 through CBD and renewal area
	Nebraska	Omaha	Abbott Drive and redevelopment construction in CBD
8	Colorado	Denver	Street improvement along Colfax Street to implement 16th Street Transitway Mall
	Montana	Missoula	Road widening of local streets and beautification efforts[a]
9	California	Oakland	Construction of ramps from Grove-Shafter Freeway (I-980) to Oakland City Center Regional Shopping Center
		Sacramento	Construction of parking structure under I-5
		San Francisco	Reconstruction of Embarcadero Freeway
10	Oregon	Portland	I-5 ramp relocation and downtown redevelopment[a]
	Washington	Seattle	Alaska Way Viaduct
		Spokane	Northriver Drive and CBD redevelopment

[a]Reported use of HUD funds.

be relocated. Capital assistance funds totaling $16.5 million will be provided by UMTA to support station relocation in the Triangle Area. Joint implementation of these measures will allow more productive use to be made of the now underutilized land and encourage the revitalization of the area.

The revitalization projects in Lewiston and Cambridge illustrate the causes of blight and associated mitigative measures. Table 2 summarizes similar information for the 35 cities. Because of the exploratory nature of this research, only the frequency of association between causes of blight and mitigative measures can be shown. More precise information on which mitigative measures are effective in alleviating specific blighting conditions will come from detailed case studies to be completed by November 1980.

An example of the information currently available is found in the Missoula, Montana, urban renewal plan, which mentions traffic congestion and lack of public facilities (sewers), aesthetic and design values, and parking as causes of blight. The transportation-related mitigation measures include TSM and provision of parking, pedestrian, or bicycle facilities and an ARZ. The mitigative measures appear to be mostly related to traffic congestion, lack of parking, and possibly aesthetics and urban design. Agreement between totals for mitigative measures in the two preceding tables should not be expected, because each measure may have been applied to more than one cause in the same city and consequently may be counted more than once. Further research will show which mitigative measures are actually effective in remedying which causes.

The six cities in which aesthetic or urban design values were a problem proposed mitigative measures that would readjust existing highway facilities or reduce demand by providing alternative modes. These six cases do not include construction of new highways, which are often very difficult to integrate into the aesthetic and design milieu of the CBD. In cities that mentioned the decline of the CBD, it is worth noting the number of times highway and urban renewal planning or community facilities were coordinated (14 times). Traffic congestion is associated with TSM and the provision of new highway facilities.

In the category of project cost, a balance between high-capital and low-capital projects was found. As the table below indicates, at-grade roadways are the most frequent type of project:

Characteristic	Number of Projects
Cost	
High-capital	19
Low-capital	17
Type	
Elevated roadway	8
At-grade roadway	14
Depressed or tunnel roadway	2
Unknown	12

A project was characterized as high-capital if one of the mitigative measures included construction of a major new facility (pedestrian facilities, bicycle facilities, and buffering were treated as low-capital measures). Low-capital projects tend to be associated with highway-related causes of blight, such as nonconformance of structure with aesthetic or urban design values, which seem to require low-capital measures (note that projects may cite more than one cause):

Cause of Blight	Number of Projects High-Capital	Number of Projects Low-Capital
Highway-related		
Nonconformance with aesthetic or urban design	2	4
Noise or air pollution	2	2
Space for right-of-way	0	1
Area-related		
Decline of CBD	6	2
Traffic congestion	5	2
Lack of access	4	1
Incompatible land uses	4	0
Lack of community facilities	0	1
Age of building	2	1
Lack of parking	0	1
Total	25	15

High-capital-intensive projects are more likely to show area-related causes, such as decline of the CBD, traffic congestion, lack of access, and incompatible land uses, as causes of blight. Decline of the CBD does not necessarily presuppose capital-intensive solutions but, in the cases available for this study, it is often associated with construction of an expressway. In Boston and Washing-

Table 2. Causes of urban blight and associated mitigative measures.

Cause	Number of Cases	Number of Measures Applied: Highway-Related A	B	C	D	E	F	G	H	I	J	K	Area-Related L	M	Total
Highway-related															
Nonconformance with aesthetic or urban design values	6		2	3	2	3	2			3	1		3	1	20
Noise or air pollution	4		2	4		3	2			3	1	2	4	3	24
Space required for right-of-way	1		1						1	1			1	1	5
Area-related															
General decline of CBD	8	5	5	3	7	1		1	1		1		7	7	38
Traffic congestion	7	3	1	3	1	1	1	1					2	2	15
Lack of access	5	4	1	1		1	2			1			2	3	15
Incompatible land use	4	2	1	1	2	2	2	2					2	2	16
Age of buildings	3	1	1	2	2	3		1				1	2	2	15
Lack of parking	1		1	1	1	1									4
Lack of community facilities	1		1	1	1	1									4
Total		15	16	19	16	16	9	5	2	8	3	3	23	21	156

Note: Symbols for measures are as follows: A = construction of expressway, B = construction of parking facilities, C = TSM measures, D = ARZ or transit mall, E = pedestrian or bicycle facility, F = reclamation of land from transportation use, G = construction of CBD arterials, H = air rights and joint development, I = demolition of highway, J = construction of transit facility, K = buffering adjacent land uses from highway, L = coordination with urban renewal, and M = coordination with construction of community facilities.

ton, D.C., the problem of incompatible land uses arose around expressways that formerly separated areas of different predominant land uses. As land uses changed because of the revitalization of some areas, the expressways no longer served to separate land uses and became incompatible with their surroundings.

In two of the three cities that cited the age of buildings as a cause of blight, transportation measures were coordinated with urban renewal projects.

Information provided on the other elements of the study is not extensive. Only nine projects had estimates of increased land values adjacent to the project. These estimates averaged $90 million for the entire revitalization effort. Four of the estimates were from feasibility studies. Highway costs are available, whereas the contributions to urban living and the financial proposals depend on the mitigation measures. Information on local citizen support was available for only a handful of the recommended projects. Four, including a joint development project, are known to lack citizen support; two are supported by citizens; and two are strongly supported by local government. Only six recommended projects for which fact sheets were prepared are completed. These projects are located in Poughkeepsie and Elmira, New York; Louisville, Kentucky; Charleston, West Virginia; Albuquerque, New Mexico; and Sacramento, California. The other projects are either under construction or planned.

The scarcity of completed projects may indicate that the use of mitigative measures to combat urban blight adjacent to highways in CBDs is a fairly new concept for which there currently exists only a small body of experience to date. Until recently, scarce highway funds may not have been considered for high-cost joint-development projects or for aesthetic treatments for highways, since such projects do not necessarily improve traffic flow. TSM funds have been awarded mostly in the name of traffic improvement and have not been part of any formal revitalization program.

CONCLUSIONS

As a result of this exploratory study, several preliminary generalizations can be made:

1. A considerable number of cities have already begun or planned highway-related improvements to mitigate urban blight adjacent to highways in CBDs.
2. The majority of the cited causes of blight stem from characteristics of the area in which the highway is located rather than from characteristics of the highway facility itself.
3. Low-capital mitigative measures are used as often as high-capital measures.
4. Low-capital projects tend to be associated with highway-related causes of blight.
5. High-capital projects tend to be associated with area-related causes of blight.
6. One-third of all mitigative measures entail coordination with urban renewal and construction of community facilities.

These observations suggest that some metropolitan planning organizations have already taken the initiative in mitigating blight with the aid of existing federal programs. Based on the information collected during the reconnaissance effort, eight case-study cities have been selected for further investigation. They are Charleston, West Virginia; Fort Worth, Texas; Portland, Oregon; Boston; Detroit; San Francisco; Seattle; and Washington, D.C.

The case studies will include field work and an analysis of urban design problems as well as feasibility and cost-benefit elements. They go beyond the scope of this exploratory study and will provide detailed information required by Congress.

Although this study could only suggest preliminary conclusions, its analysis of secondary information has served to focus the research effort in the more extensive field study. For example, the exploratory study found many cities using combinations of highway and urban-renewal-type mitigative measures. These combinations suggest institutional and procedural complications. For these and other reasons, the report to Congress will address intergovernmental relations, methods for implementation of mitigative measures, and appropriate FHWA policies and procedures.

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Highway Access Management: Preserving Public Investment in the Highway Network

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Uncontrolled access to arterial highways from abutting development frequently results in rampant strip development in highway corridors. Traffic entering and exiting the highway through private access points interferes with the movement of through traffic, and the result is congestion and a reduction in the capacity and safety of the highway network. A prototype program for highway access management is introduced that uses regulatory mechanisms to minimize interference from private access points, thereby bringing about the more efficient use of the existing highway network and reducing the need for new highway construction or expansion of existing facilities. The legal access rights of owners of abutting land, the regulatory authority of state highway departments, and the role of cities and towns are identified as critical factors in the establishment of an effective access-management policy. A task list is presented that attempts to address each of these factors and resolve the conflicting goals of the state, local government, and private developers.

In recent years, transportation planners have had to work in a rapidly changing environment. The direct financial costs of large-scale construction projects have risen tremendously and will continue to do so. In addition, the indirect costs associated with these projects have also risen. The environmental and social effects of highway or subway construction must now be analyzed and accounted for in great detail. As a result, there has been a gradual shift away from large-scale, capital-intensive projects whose purpose is to add significantly to the transportation infrastructure. Short-range, low-capital projects intended to bring about the more efficient use of existing facilities are now considered more feasible from a variety of standpoints.

We have reached a point at which transportation investment must be reoriented toward these types of projects. The scope of new highway construction in the years ahead will be extremely limited as both direct and indirect costs escalate beyond the point at which such projects can be considered cost effective. The emphasis in highway planning must be placed instead on the maintenance of existing roads and on the use of techniques to improve traffic flow and increase capacity on the established network.

Regulatory strategies can also be effective in bringing about the more efficient use of existing facilities. One such strategy is management of highway access. Vehicles moving onto and off arterial highways reduce the effective capacity of the road because entering and exiting traffic interferes with through traffic. Through regulatory mechanisms, access to these highways can be managed in such a way as to minimize this interference and thereby increase the effective capacity of the highway.

The purpose of this paper is to present a prototypical policy for management of highway access that will result in the more efficient use of existing highway facilities. First, the goals and motivations of an access policy are presented. Then, some of the critical factors that influence the development and implementation of an access-management program are examined. Finally, a prototype program of access management, including a policy statement, organizational and political components, and a task list for program implementation, is presented.

DEFINITION OF ACCESS MANAGEMENT AND PROGRAM GOALS

Access management can be defined as the selective implementation of access-control techniques and regulations for the preservation of the utility of the highway network. These techniques vary widely, from highway design (the construction of median barriers or curbs) to those that are more regulatory in nature (restrictions on driveway location or use). For example, the Interstate highway system prohibits access except at designated interchanges, thereby providing a consistently high level of service. In this case, access restrictions are established on newly constructed facilities. More serious problems exist, however, on uncontrolled-access facilities where political, physical, or financial constraints prevent roadway expansion or reconstruction intended to provide additional capacity. Many of these highways have attracted substantial commercial growth and have experienced increased traffic volumes as more commercial establishments locate on land directly adjacent to the highway. These increased traffic volumes stimulate additional commercial development and thus bring about a still greater increase in traffic volume, which eventually leads to severe congestion and safety hazards in the highway corridor. Strip development along uncontrolled-access arterials is the most common manifestation of this phenomenon. Highways along which strip development has occurred are the prime targets of an access-management program.

A major objective of access-management policy is to preserve the traffic-carrying capacity of existing highways without requiring massive expenditures for reconstruction or expansion of these facilities. In more general terms, such a program is a mechanism for ensuring the most effective use of public investment in the transportation network. In addition, access management can result in greater coordination between the characteristics of the highway network and community growth and economic development within the corridor. Finally, it can bring about greater awareness among local officials of vital growth issues that must be faced in planning long-range community expansion.

The use of access management for the protection of the highway network is becoming much more common as a number of states recognize the potential benefits that such a program offers. In the state of Washington, direct commercial access to state highways has long been prohibited (1). The Oregon Department of Transportation has stated that "the department will make the maximum effort to protect and maintain the existing highway system so as to retain optimal conditions that will not be detrimental to the economy of the community and to the public well-being" (2). In conjunction with this, Oregon has an access-control program on all freeways and primary arterials and on many secondary arterials. Wisconsin has for a number of years had laws that empower the Wisconsin Highway Commission to enact a comprehensive access-management policy. However, only recently has there developed momentum in this direction, primarily as a result of the interest of agencies other than the highway commission in the potential of such a program (3). In contrast, some states are beginning to recognize the need for access management on a much smaller scale. Tennessee, for example, has established cooperative planning procedures to minimize the potential dangers of unrestricted access along a single corridor of one state highway (US-129).

Although these states and several others have begun to examine the concept of access management, there are many more states that have not taken steps in this direction. Such efforts should be made before unrestricted access results in the functional obsolescence of major segments of the highway network at a time when major network improvements and expansion are not feasible.

FACTORS THAT AFFECT PROGRAM DEVELOPMENT AND IMPLEMENTATION

Access management can be viewed as a strategy that deals with problems related to the insufficient capacity of the highway network through low-capital, and primarily regulatory, mechanisms. However, many legal and political factors could potentially affect the implementation of a state program for management of highway access. This research has identified three such factors: the rights of owners of abutting land ("abutters"), the use of state regulatory powers, and the role of local communities in the development of an access-management program. Each of these is discussed below.

Abutters' Rights

The owners of land abutting arterial highways (other than limited-access highways) have, as a condition of ownership, certain property rights related to highway access. The interpretation of these rights varies slightly from state to state, but a general doctrine of the rights of abutters can be drawn from judicial decisions and judicial interpretation of existing statutes.

An abutter is entitled to compensation if

1. All access to the highway network is totally denied,
2. The access permitted the abutter is insufficient for the "highest and best use" of his or her property,
3. Special injury is done to one specific property through access restrictions,
4. The highway that fronts the otherwise landlocked property is rebuilt as a limited-access facility, or
5. Relocation of highway access points impairs the abutter's use of his or her property.

An abutter is not entitled to compensation if

1. Access is circuitous or reasonably regulated,
2. Access restrictions are sufficient for the "highest and best use" of the property,
3. No special injury is suffered,
4. A new limited-access facility is constructed on new right-of-way, or
5. Site design or parking-area changes required to improve the highway necessitate the relocation of access points.

Abutters have the right to reasonable access to the adjacent highway, not unlimited access. A critical issue in the interpretation of this right is the extent to which the state or the highway authority can restrict it without compromising an abutter's rights and having to provide the landowner financial compensation.

The number and location of access driveways to a particular land parcel may be regulated by the highway authority. In addition, the access permitted to an abutter may be indirect or circuitous; that is, because of one-way streets, median barriers, or service roads, an abutter may be required to travel a longer distance than desired to get to his or her property. Direct access to a highway may also be denied if the abutter still retains reasonable access to the highway through the local street network. It has generally been left to the courts to determine, on a case-by-case basis, when access limitations are reasonable. Finally, reasonable restrictions on the design and construction of the driveway itself are appropriate uses of government regulatory power.

The access rights of abutters are protected by one general principle: The access granted to an abutter must be sufficient for the property to be developed to its highest and best use. For example, the owner of a shopping center cannot be restricted to a driveway of a size normally considered standard for a single residential home because it would not accommodate the large traffic flow normally expected at a shopping mall. If a land parcel is zoned for industrial or commercial development, or if there is a significant probability that the zoning might soon be changed to one of these designations, the property owner must be permitted access that is suitable to the type and quantity of traffic normally expected as a result of such development.

This obviously implies that there should be a strong relation between the capacity and design of a highway facility and the zoning of adjacent property. Because these two factors are frequently the responsibility of different jurisdictions, this relation is often unclear or nonexistent.

An abutter is not entitled to direct access to new limited-access highways or freeways. However, if an existing highway is redesignated as a limited-access way or if a new limited-access road is constructed on the right-of-way of an existing uncontrolled facility, then the owner is entitled to compensation for the loss of direct access. Finally, if an abutter has access to a highway that is in some way deficient or dangerous to the general public, that access can be revoked without compensation. In addition, if a highway department makes corridor improvements and decides to relocate existing access driveways as part of the improvement program, the abutter must pay all costs for laying out his or her property to use the designated access points. These two factors provide state highway departments with considerable leverage in making improvements to existing highways that have unsafe access patterns.

Role of the State

State highway departments and commissions have the responsibility for the design, construction, and maintenance of highways, including those on the Interstate network. Because of this, the primary concern of the state in relation to access management is the successful preservation of the functional capabilities of the highway network. There are a number of ways in which the state can successfully achieve this goal.

Each state has the ability to legislate and enforce regulations and restrictions on behalf of the public welfare as long as these regulations do not interfere with private property rights. The single most important regulatory process that should be used to manage highway access is the review of driveway permit applications.

Most states have at least a rudimentary procedure for the opening of new driveways onto state-controlled roads, although the actual procedures and regulations vary widely from state to state. Typically, a potential developer of land adjacent to a highway applies to the highway commission for a driveway, or "curb-cut", permit. This application is reviewed on the basis of specified criteria and is either approved or rejected by the appropriate office. When this review power is used correctly, it can be very effective in the management of highway access.

First, the permit process should specify design standards for driveways. These specifications should include the number of driveways permitted per parcel or per length of highway frontage, the visibility requirements, the spacing of adjacent driveways, and the dimensions of the driveway itself. These driveway standards should be linked to both the type of development being proposed and the type of highway facility on which the parcel is located. Large commercial or industrial developers may be required to provide left- and right-turn lanes and merge areas, whereas residential developers may not be required to provide such features for their access points.

Driveway specifications can most easily be linked to highway type by using highway functional classifications. In the state of Washington, for example, there are different sets of design requirements for driveways on primary arterials, secondary arterials, and local streets. In this way, requirements can be made more strict on roads that carry a higher percentage of through traffic so that interference from entering and exiting traffic can be minimized. On roads that function primarily as collector-distributors, these requirements are less strict and direct access is more readily available.

The permit process should explicitly set forth the power of the state to continue to regulate the location and use of the driveway after it has been constructed. In Alaska, for example, permit regulations state that the granting of a permit does not waive any state right to direct the removal, relocation, or maintenance of the finished driveway. In addition, driveway permits can be revoked if "the use and presence of the driveway or approach interferes with the required use of that portion of the right-of-way occupied by the driveway, or constitutes a hazard to traffic" (4).

Permits can also be limited so that they become void whenever the use of the land changes from what was described in the original permit application. In this way, a new development cannot automatically use the driveway or driveways from a previous development; the developer must apply for a new driveway permit based on the volume of traffic expected from the new development.

All of these driveway permit regulations are designed to ensure that the highway department has continuing control over the location and design of access points. Should the state at some time wish to make corridor improvements, its right to relocate, redesign, and, in some cases, remove existing access driveways has been clearly stated.

Some states have carried the regulation of driveway permits even further than this. In Oregon, for example, access points have been assigned to all land parcels that adjoin state highways, whether or not any development has taken place (5). This guarantees that all spacing and design guidelines can be safely met and requires potential developers to consider the location of the access point as a constraint in site design. There also exists a somewhat different permit process through which landowners can request additional or relocated access driveways, subject to the approval of the highway commission.

In New Orleans, developers cannot obtain a building permit until they have received a driveway permit from the highway commission (1). This is an alternative way to ensure that developers consider driveway location during the design phase, since construction on the site is prohibited until the building permit is granted. Similar links can be made between driveway permits and land subdivision so that, when a large parcel is subdivided into smaller plots or home sites, access permits must meet with state approval before resale of the individual properties takes place.

In addition to driveway permits, the state has other regulatory controls over highway access. All state highway departments have the authority to establish traffic regulations, which generally include traffic signals, vehicle restrictions, and the construction of curbs, medians, and other barriers to control the flow of traffic. Although this authority is usually based on providing for the safety of the traveling public, enabling legislation for this authority should also define the preservation of the capacity of the highway network as a basis for these regulations.

Most state highway departments also have some legislated authority to construct limited-access highways (such authority was the basis for the construction of the Interstate highway system). This authority can be expanded to permit the designation of a network of controlled-access highways within the state (highways on which access is not totally restricted but is subject to strict regulation and scrutiny by the state highway department). Wisconsin has a statute that permits such a declaration to be made for rural portions of state highways whose average daily traffic exceeds some threshold, but there is no reason why this authority could not be expanded to allow any portion of the state highway network to be designated a controlled-access road.

Another source of state authority is the principle of eminent domain, which empowers the state to violate private property rights when it is deemed necessary in the best interests of the public at large and is usually used as the legal basis for taking land for some public purpose. It also requires the state to compensate the property owner for damage done or property taken. An obvious example of the use of eminent domain is the taking of land for the construction of a highway, but it can also be used more subtly to allow the state to "purchase" the right of access to a state highway.

As previously described, access can be restricted as long as these restrictions do not interfere with the abutter's use of his or her property. As soon as the restrictions become too strict, the individual's property rights have been damaged and he or she is entitled to financial compensation. Under eminent domain, the state can establish access regulations that would otherwise be considered illegitimate because the state repays the property owner for excessive damage done through those regulations. Therefore, whenever the state deems it essential to the public welfare that access be restricted past the point where the land can be developed to its highest and best use, it can invoke eminent domain to pay landowners for the damage that results from loss of access.

The disadvantage of eminent domain is that the amount of financial compensation required may be considerable. Where access is denied an otherwise landlocked parcel, all development on the site is effectively prohibited and the state for all practical purposes must buy the land from its owner. For a site that might potentially have contained a large commercial or industrial development, this could be prohibitively expensive. In addition, excessive use of eminent domain would not be acceptable to local governments that may wish to encourage development.

Role of the Local Community

Local communities must play a critical role in the development of an access-management policy. Even though their interests most frequently conflict with those of the state, local communities can benefit considerably from a state access-management plan that is properly targeted and implemented.

Establishing substantial industrial or commercial development in order to provide a sound tax base is often of primary concern to local communities. State highways that pass through towns provide ideal locations for such development, and any restrictions on access to these highways interferes with their potential for attracting industry or business. On the other hand, strip development along state highways is generally unattractive and blighting and undesirable to a community in spite of the potential tax benefits it may bring. A correctly designed access-management program can effectively prevent unrestricted strip development while permitting the economic growth that is essential from the local community's point of view.

Cities and towns can exercise several types of regulatory controls in support of a state access-management program. As mentioned earlier, building permits can be linked to driveway permits so that a developer must consider, as an important factor in designing a plan for the abutting property, the location of a driveway that is safe and that provides adequate capacity. Local zoning regulations can affect highway access in a number of ways. They can reflect support for the curb-cut regulations that have been established at the state level, either by duplicating those design requirements or by stating requirements for compliance with state standards for driveway permits. It is particularly important that local zoning codes affirm different sets of design standards for different types of development; the establishment of different regulations for different land uses is a long-established and well-accepted function of zoning regulation.

Zoning can also be used to encourage improved site and circulation-pattern design. Parking areas, for example, are frequently designed so that vehicles that are waiting for or moving in and out of parking spaces may interfere with traffic on the abutting road. In this case, it is not the availability of access that disrupts the highway but the way in which internal design affects the use of the access point. Zoning regulations could require that all vehicle parking be located at the rear of abutting buildings, away from the highway, or that sufficient vehicle "storage" be provided as a buffer to prevent vehicles that circulate on the property from interfering with highway traffic.

Summary of Important Factors

In summary, then, many factors must be considered in the design and implementation of an access-management program. Owners of abutting land have the right to adequate access to the highway network and the absolute right to develop their property to its highest and best use. Government regulations and restrictions can therefore be used to limit access to some extent but, when the use of the property is interfered with, the landowner must be compensated for his or her losses according to the legal concept of eminent domain. State government has several regulatory mechanisms at its disposal. Regulation of driveway permits is the most important of these, others being traffic regulation and the creation of limited-access highways. Eminent domain is invoked (a) whenever access must be so restricted that the abutter must be compensated, (b) when land is acquired for new highway construction, and (c) when limited-access highways are built in existing rights-of-way. Local communities play a critical role in access management because their goal of economic growth may conflict with any kind of access restrictions. On the other hand, local zoning and building regulation can give tremendous support to an access-management program if the program is designed in such a way as to support, rather than be in conflict with, local community goals.

All of these issues must be dealt with in the development of an access-management program. The successful implementation of the program depends on the explicit recognition of all of these factors.

PROTOTYPE ACCESS-MANAGEMENT PROGRAM

Access management will of necessity become a major new focal point of highway departments. This will happen more quickly in some states than in others, and the specific techniques of access control that should be used will also vary, depending on the size of the state highway network, the intensity of development along the network, and constraints on budget or personnel levels. Because this variation may in some cases be great, the access-management program presented here is more correctly described as an open framework in which states can develop comprehensive, individual programs that properly address their own specific needs and problems.

Access-management programs will almost certainly be moderately capital intensive in nature. Although many of the strategies encompassed by such a program are regulatory and therefore have no associated capital expenditures, successful program implementation will require substantial commitments of funds in the following areas:

1. Personnel expenses will be substantial. Large staffs will be needed to oversee and administer the access program and to participate in the educational and cooperative planning programs that are outlined later in this paper.
2. Eminent domain will be invoked to some extent by nearly all states that are involved in access management, although this again will vary from state to state. In more highly developed states, the funds required to compensate property owners for loss of or damage to their property may be quite substantial, particularly if eminent domain is used along entire highway corridors.
3. Funds will be required for construction projects when states deem it necessary to expand or make other improvements in an existing corridor.

Highway planners must come to the realization that a substantial commitment of funds may be required for the successful implementation of an access-management program. Even though much of the personnel and funding could actually be supplied by shifting resources from existing construction and maintenance efforts to the new program, this would often prove difficult to accomplish. There must be strong support for the program, both from the leadership in the state highway department and often from the state legislature, which must allocate funds for the program.

It is worth noting that an access-management program, although primarily regulatory in nature, is in several ways very different from strategies that are grouped in the transportation system management (TSM) category. The goals of both are similar in that they attempt to avoid large capital outlays through the more efficient use of existing facilities, but past this point the resemblance begins to break down. Most TSM-type projects are relatively small in that they may address a single facility (e.g., an exclusive bus lane along a highway corridor) or a single geographic area (e.g., automobile-restricted zones). In addition, most TSM projects are short range and easily reversible if not successful. Access management, on the other hand, is a comprehensive, statewide effort that is much larger in scope than most TSM projects and cannot be discontinued in the way that most TSM projects can. As a result of their size and other characteristics, access-management programs are also far more expensive than normal TSM projects; as mentioned earlier, significant capital expenditures may be required in some states for successful implementation.

Now that some of the broader descriptors of an access-management program have been examined, a fairly specific implementation plan can be outlined. The plan presented here is not intended as a step-by-step instruction manual on access management, but it does identify several specific tasks that must be accomplished. These tasks can generally be placed in one of three categories: program management, planning coordination, and program implementation.

Program Management

Program management encompasses all tasks that are primarily administrative in nature. The most important of these tasks is the development of a policy statement on access management. The policy statement should cover several major areas: It should define the goals of the access-management program, describe the important interest groups and summarize their concerns, and identify the various mechanisms through which the program will be implemented and enforced. Because the function of the policy statement is to serve as a unifying base for the entire program, it is important that it be given strong support by a variety of institutional sources, including the highway department, the state legislature, the governor's office or staff, local governments and zoning boards, and regional and local planning agencies.

A second major task is the allocation of responsibility for program execution. Generally, some branch of the highway department will be the lead group, but many other branches may also be involved. It is the responsibility of the lead group to identify the roles of all participants. Review of driveway permits, legal support, state-local coordination, and enforcement, in addition to more obvious tasks such as network planning, should be assigned to appropriate groups or agencies. These assignments depend heavily on the existing institutional structure in each state, but it is probably most beneficial to keep most of these functions centrally located in a single division or office so that the policy statement is not interpreted differently by separate groups.

A third task in program management is the implementation of legislative and regulatory changes that provide the state with adequate levers of control over highway access. Some states, such as Wisconsin, may not need any significant changes in existing laws or regulations. Others, such as Massachusetts (6), may require some clarification of existing statutes as well as significant regulatory changes. Still other states may require even more dramatic revisions. In any case, all laws and regulations should be tied directly to the highway department's policy statement on access management, clearly spell out the responsibilities of all actors, and identify all design standards and requirements.

There are two major benefits to be gained from this task:

1. Because all design requirements are clearly spelled out, developers and local communities will be able to plan development with no uncertainty about access to the highway. Since access decisions will not be discretionary, investment decisions and site design can be based on the established regulations.
2. Because all statutes and regulations are unified under the policy statement, court decisions on individual cases in which access has been restricted may be more supportive of the highway department. Without a comprehensive program, individual landowners are more likely to be awarded damages if their access is limited while their next-door neighbor's is not. But, if these access restrictions are applied broadly to many property owners in support of the welfare of the general public, the courts will be less likely to award damages.

A final project-management task is the development of local regulations in support of the state access-management program. This task requires a substantial amount of interaction with regional and local officials and is critical to the successful implementation of the program. As mentioned earlier, local zoning regulation can circumvent the state's best efforts unless it is tied in with the state driveway specifications in some way, so the importance of local support for the state program cannot be overstated. Ideally, local regulations should ensure that building permits cannot be obtained without a valid driveway permit and that all development conforms with state standards for driveway location and design. In addition, zoning requirements regarding site design and circulation patterns within the development can yield additional benefits in reducing the amount of interference between through traffic and traffic moving onto or off the road. To a large extent, the successful establishment of these local regulations depends on the planning coordination tasks outlined below.

Planning Coordination

Planning coordination includes two major tasks. The first of these is the establishment of educational programs through which the access-management program can be described and justified for local and regional planners. Many local officials are unaware of the importance of highway access as it affects highway capacity and safety as well as local development and economic growth. They will probably react negatively to an access-management program because the use of access controls implies that restrictions will be placed on local communities by the state. An educational program should stress the potential benefits that local communities can experience through access management, such as the control of strip development, and should emphasize that access controls are not intended to interfere with economic growth and development but only to ensure that this development takes place in such a way as to maintain the functional capability of the highway network.

It is as part of this task that a major institutional conflict must be resolved. Cities and towns see it as the state's responsibility to provide adequate highway transportation and to make improvements where the network is congested or otherwise deficient. The state, on the other hand, interprets extensive development by cities and towns as something that is damaging to the highway network and does not feel that it should be responsible for improving portions of the highway network in locations where local government's encouragement of extensive development generates traffic that exceeds network capacity. Clearly, some balance should be established so that the state bears its responsibility for the maintenance of the highway network and the community encourages well-planned and directed growth that does not conflict with the responsibility of the state.

A second major task in this category is the establishment of cooperative planning among the state highway authority, local planners, and developers. Establishing updated statutes and regulations—setting the ground rules for development—will aid significantly in this task, although local planners and developers may resent the establishment and enforcement of such regulations. Cooperative planning efforts by the state, however, can help to show other interest groups how to successfully accommodate development while complying with the established access regulations. A good example of this kind of cooperative planning occurred in Tennessee along US-129, where the state highway department, in conjunction with new access regulations, provided preliminary site-planning assistance to owners of abutting land. The landowners were then free to take any acceptable design ideas to other companies for further development.

By assigning staff members to work with local officials and developers, a state highway department can help to ensure that local groups will know about potential projects early in the planning stages so that they will be able to provide input to the developer's initial site design or to a community's land use plan. In addition, building a good working relationship with local planners will help to streamline the establishment of local regulations in support of the entire access-management program.

Program Implementation

Program implementation incorporates a number of tasks that will vary from state to state. The first is a highway survey that examines all portions of the state highway network. Each highway segment should be classified as to the size and capacity of the road, levels of existing and potential development, existing and potential safety hazards, and functional classification. When this is completed, certain highway segments may be identified as being of critical importance. For example, a roadway segment that is undergoing heavy strip development and may soon become congested would be a target for immediate action under the access-management program.

When the highway survey has been completed, the state must proceed with the development of a master plan for state highways. It is in this area that substantial variation among states will occur. Some states may find it necessary to declare a network of state highways to be controlled-access highways and develop standards and specifications appropriate to that designation. Other states might declare certain segments to be controlled-access highways and develop a long-range program for the acquisition of access rights on less critical portions of the network. Still other states might find it necessary to apply access controls only on a spot basis. These decisions must be based on a wide variety of factors, including existing and predicted traffic levels, development potential, and fiscal and personnel constraints that might limit the scope of state activity.

Finally, the state must develop a programmed implementation plan that specifies the state's priorities in establishing the access-management program. For example, a state might declare its first priority to be the purchase of access rights along rural portions of state highways and its second priority to be the construction of service roads on critically congested portions of the network. These projects must be programmed so that the projects that are given priority are matched with expected funds and scheduled for implementation at some point in time. Again, it is expected that priority rankings will vary widely among states. More urban states, for example, would probably not give high priority to corridor improvements in congested areas where strip development has occurred because the required expenditures for such a program would be enormous. These states might prefer instead to concentrate on stricter specifications and review of driveway permit applications.

Task Summary

The program tasks described in the preceding discussion can be summarized as follows:

1. Program management—(a) development of a policy statement, (b) allocation of responsibility for program execution, (c) implementation of legislative and regulatory changes, and (d) development of local regulations;
2. Planning coordination—(a) development of educational programs and (b) establishment of cooperative planning; and
3. Program implementation—(a) state highway survey, (b) development of master plan, and (c) programmed implementation plan.

Although this list is not exhaustive, it does include those tasks that are most critical to the implementation of an access-management program. It is clear that the efficient use of the highway network through primarily regulatory means is an institutionally complicated procedure. The interests and jurisdiction of many groups must be accounted for, and the establishment of working relationships between these groups in essential.

CONCLUSIONS

Because the network of arterial highways in this country is an essential portion of the transportation infrastructure, the preservation of the network is critical. The single most important factor in maintaining a high level of service is the effective management of access to these highway facilities. It is widely observed that the availability of uncontrolled access to a highway from commercial, industrial, and/or residential property can lead to rampant strip development along the highway corridor. The movement of vehicles through these strips causes congestion and increased safety hazards and results in severe deterioration in the level of service provided by the arterial.

Strip development and its associated congestion were once alleviated by constructing bypass routes along new rights-of-way, but increased costs have made this impractical. Now, it is essential that this type of deterioration in highway service be prevented. Through management of the availability of access to the highway network, economic development and community growth can still be achieved, but the negative effects of this growth on the capacity of the highway network can be minimized.

A key issue in the development of an access-management program is the property rights of owners of abutting land, which include their right of reasonable access to the highway network and the right to develop their property to its highest and best use. Through regulatory mechanisms, the state can limit abutters' access until one of these two rights has been violated, at which time eminent domain must be invoked and the landowner compensated for damage done to his or her property.

Another issue in developing an access-management program is the conflict between the state's desire to maintain the highway network and the desire of cities and towns to use the network as a basis for development. The use of local regulatory controls becomes extremely important because they are capable of severely affecting the potential success of an access-management program.

The prototype access-management program attempts to recognize these major factors and present a list of important tasks that are critical to successful program implementation. Because states vary widely in their need for access management, the task list is not intended to be exhaustive but merely representative of what a state must accomplish. Given the current environment of transportation planning, the level of effort required to accomplish these tasks will increase as access management becomes more important in future years.

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Abridgment

Accommodating Urban Development While Preserving Close-In Natural Landmarks

Romin Koebel

The importance in the life of cities of preserving open space and saving endangered natural landforms is examined. The spatial development of Columbus, Ohio, and the effort to preserve that city's natural topographic features in conjunction with development are cited as an example. The part played by the concept of transfer of development rights in preserving natural landmarks is also discussed.

Open space, plazas, and natural areas enhance environmental quality, amenity, and area ambience. In the past, cities have gone to great lengths to create open space: Georgian London laid out handsome residential squares; in Paris, French noblemen created Renaissance plazas where there had previously been urban squalor. Provision of open space has figured prominently in recent strategies to rehabilitate the quality of the spatial environment. Boston's Government Center Plaza and lower Manhattan's Chase Manhattan Plaza, carved out of the existing urban fabric, triggered dramatic economic revival by restoring confidence among investors and builders. As rehabilitated structures and new, privately financed construction quickly surrounded the new spaces, real-estate tax revenues soared.

In Columbus, Ohio, the configuration of the water-course system and its associated landforms profoundly affected the evolving spatial pattern of the city. The original grid, aligned perpendicular to the bridge across the region's principal watercourse, established the directions of the region's two main growth shapers, High Street and Broad Street. For a while, these axes, intersecting at right angles and offset from the principal points of the compass, governed the alignments of new plats. But, as expansion continued, development began to be aligned with the all-encompassing national grid. Older pockets of development, such as outlying North Columbus with its skewed grid of small, square blocks, were enveloped by the new pattern.

"Breaks" occurred at the interfaces between different gridirons. Glen Echo Ravine, deeply indented in the bluffs above the meandering Olentangy River, was once part of a popular amusement park at the end of the streetcar line. A major break occurred where Glen Echo Ravine intervened in the path of northward development along High Street. There was conflict between the geometries of interpenetrating grids, which resulted in a wedge-shaped fracture zone with offset intersections; small, odd-shaped blocks; and a medley of incompatible uses. Although one artery is aligned to the regional grid, a second artery takes its directional cue from the diagonal slash of High Street, which is carried over the ravine on a broad earthen embankment.

Over the years, land uses in Columbus underwent major changes. In response to new demand, sites were cleared for new construction. Commodious streetcar barns gave way to a string of service stations; these, in turn, are increasingly under pressure from fast-food franchisers. To accommodate new building sites, the stream in the ravine bed was enclosed in a culvert to permit widening of the High Street embankment. Recreational tastes changed as mobility increased with the advent of the automobile. In the 1930s, as the popularity of Olentangy Park waned, a civic-minded local entrepreneur acquired that property for the purpose of developing rental housing. The site was highly prized for its accessibility and unique scenic assets. Inspired site planning took full advantage of the site's attributes—its ravines and bluffs, woods and meadows. A distinguished site plan resulted: a sequence of courtyard-like spaces extending south and wrapping around the major ravine. Although it was an instant success, only the northern part of the plan for Olentangy Village was implemented. However, the site's zoning classification—apartments—is a reminder of the original intent.

There was widespread concern when a regional grocery chain announced plans to build a "superstore" with more than 500 parking spaces in the Glen Echo Ravine area. The plan involved creating a large, flat, "tabletop" site by filling in the scenic ravine. In order for the plans to go forward, a zoning change from residential to commercial was needed. Despite vocal opposition, the city council granted the change. Opposition to the scheme was led by a broad alliance of concerned citizens that called itself Citizens Against Glen Echo Rezoning. This group orchestrated a successful campaign to overturn the rezoning and, when the issue ultimately wound up on the June 1978 ballot, the zoning reverted to its residential classification.

A subsequent scheme for multistory housing at the ravine's southern edge was also opposed. Instead, southward extension of Olentangy Village was advocated, and the remainder of the property—the ravine and the scenic south meadow—was envisaged as a park for the elderly. After dickering with the proposal for housing south of the ravine, the owners decided not to relinquish control of this key part of the property. In also rejecting the idea of selling the ravine as a park, they did, however, make known their intent not to proceed with any development until a master plan for the ravine was ready.

Like many cities, Columbus is endowed with unusual topographic features, islands of green that are close in and surrounded by development. As cities become more and more built up, difficult-to-develop natural sites that were leapfrogged over in the initial wave of urban expansion, such as Glen Echo Ravine, are increasingly becoming the focus of developers' attention. Because these areas are such an asset, the question that arises is, How can we avert the destruction of our dwindling legacy of privately owned, close-in natural areas and at the same time meet legitimate demands for development?

Clay (1) has called attention to the significance of breaks: abrupt switches in the direction and/or design of street patterns, where a gridiron encounters a steep hill, a valley, or a ravine or where a new gridiron clashes with an earlier one. Original grids, which were seldom large enough to accommodate growth, typically paralleled a town landing, a railroad, or a bridge—as in the case of Columbus. Many breaks, being highly accessible and visually prominent, are sites of landmark buildings. Natural landmarks and fracture zones are linked phenomena. Subsequent grids seldom merged easily with the original grid. Breaks form psychological as well as geographic barriers. Fracture zones may be disruptive to circulation, have a blighting influence, or be slow to develop; as such they have been sought as sites for urban renewal and/or freeways.

Thus, at Glen Echo, the clashing geometries of interfacing grids left an indelible imprint: small city blocks of irregular shape, a poor circulation pattern, and a motley variety of land uses. At one point, the spatial character changes abruptly: Densities are low and structures generally single-story, and a sense of openness and of the presence of nature prevails. By contrast, to the south, densities are higher and buildings several stories high extend without setback from side lot line to side lot line. Decisive intervention is justified; the proposed strategy of deliberate change is based not only on the need to conserve the natural environment of the ravine but also on the need to reorder the spatial environment of the ravine's surroundings.

A number of approaches could be considered. Planned unit development offers an opportunity to cluster development; overall density remains the same, but microdensities are higher. But since level areas are few, the approach could jeopardize the scenic South Meadow, although some relief could be provided by downzoning.

Transfer of development rights (TDR) is another possibility (2). This concept has aroused considerable interest as a means of saving endangered land uses. Unused development rights, generally expressed in terms of floor-area ratio (FAR), are transferred to sites at less vulnerable locations (the amount of rights eligible for transfer equals the difference between existing development and the amount of rights allowed by zoning).

Despite strong interest, TDR schemes seem flawed in several ways. They may fall victim to permissive zoning and/or indiscriminately granted variances. High FAR base levels—such as those in Chicago—work against them. The difficulties are compounded if TDRs have to compete with overly generous bonus systems. Reattachment of development rights may create a new set of negative impacts elsewhere. Excessive building envelopes on undersized lots pose a threat to valid zoning rationales. The transfer of a surfeit of development rights could have forbidding three-dimensional effects, and distribution among several sites may be impractical. The prospect of complex negotiations among multiple owners could intimidate even the most skilled of negotiators. There may be a lack of appropriate, conveniently located receiving lots. Preparation of a receiving lot for construction may incur substantial costs—e.g., the cost of the demolition of existing structures. The value of development rights may fluctuate greatly between granting lots and potential receiving lots. When experience in establishing markets is lacking, how will rights be priced? It is an underlying tenet of TDR theory that protection of assets enhances area amenity and ambience; as a result, property values rise at a faster rate than they probably would otherwise. But, although the grantor thus helps to create values areawide, he or she can partake of the benefits that accrue only in a very limited way. Once development rights have been transferred from a granting site to a transferee site, the grantor no longer has an interest and is, in effect, excluded from participation in the benefits that flow from a rise in real-estate values. The grantor is denied "a piece of the action". Benefits flow disproportionately to the owners of transferee sites, who derive substantial benefits from larger structures set in an enhanced environment.

Unless an equitable distribution of benefits is assured, TDR systems are unlikely to win acceptance. Designers of TDR systems must recognize a basic reality of urban land development—that the ability to participate in value capture is a powerful motivating force. Through an effective pricing mechanism, grantors should be adequately compensated for opportunities forgone. Owners of candidate granting lots ought not to be cast involuntarily in the role of magnanimous benefactor.

Indications are that TDR approaches have a better chance of winning acceptance if the following conditions can be met: if (a) development rights can be transferred between lots of common ownership; (b) granting and receiving lots are in close proximity to one another and real-estate values are comparable; (c) there are no competing bonus systems; (d) demand for higher-density development at candidate receiving lots is substantial and floor-area ratios set a limit on the development allowed by rights; (e) transfers are guided by an urban design framework plan; and (f) receiving lots are of a size and shape that allow additional development rights to be absorbed without creating negative externalities.

The proposed strategy is a synthesis of several regulatory techniques: transfers of development rights, traditional zoning, and the city's powers in relation to urban redevelopment, including the power of eminent domain. As indicated, the availability of transferee lots is critical. Such lots should meet specific criteria with regard to location, size, and shape. Urban renewal provides a basis for creating workable receiving lots. Several steps are involved: land assembly, selective demolition, reparceling, and parcel disposition. Zoning controls help in establishing the preconditions for an effective market in development rights. Development must conform to bulk specifications defined for each individual parcel in a comprehensive area plan. However, since only a limited amount of development is assigned as of right, developers must acquire additional rights to meet envelope specifications. A demand for development rights is created; transfers of development rights ensure that the demand can be met. In the Glen Echo Ravine case, the redevelopment area is designated as a receiving zone and the open spaces at Glen Echo are designated as a granting zone. Developers are assured of a source of development rights and owners of a market.

Area values appreciate at an accelerated rate as a result of preservation of natural features, and urban renewal controls development in accordance with an urban design framework plan. However, the success of the strategy hinges on whether landmark owners perceive the incentive as sufficiently attractive. The strategy seeks to assure landmark owners a commensurate share in accelerating area values by establishing patterns of common ownership in both receiving and granting zones. Rather than having to forgo opportunities to engage in development, which is the case when development rights are sold, owners are provided an opportunity for ongoing participation in the development process. Landmark owners may shift development potential away from the to-be-protected area to sites they own in the receiving zone; through the redevelopment area parcel-disposition process, owners acquire strategic parcels to which development rights may be conveyed in amounts sufficient to fill designated envelope specifications.

This approach will increase incentives to preserve the Glen Echo Ravine and expand the array of options by providing an alternative to the sale of development rights. It will thus enable participation in the type of development that takes full advantage of the urban design potential inherent in protecting scenic assets. It will thus permit landmark owners to participate in the economic benefits that flow from a built environment that is superior in quality to that achievable under conventional development patterns.

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Abridgment

Urban Blight and Highways in the Central Cities: Theoretical and Practical Perspectives

Arthur Politano

A basis is provided for a better understanding of the causes of urban blight and the relation between urban blight and highways. A literature review on the causes of urban blight is presented, and examples of mitigative measures taken in various cities are described. Several federal programs that could be, or are being, used to fund revitalization and development efforts in central cities are briefly discussed.

The President's urban policy, enunciated on March 27, 1978, proposes to "improve the urban physical environment and the cultural and aesthetic aspects of urban life." To guide any effort to revitalize central cities, the literature should be examined to ascertain the causes of blight. Given the coexistence of urban blight and highways in many American cities, it behooves urban observers and planners alike to examine the relationship between the two. When there is a general understanding of such a relationship, highway-related mitigation measures can be suggested and preliminary conclusions can be drawn on the applicability of these measures to reducing blight in central cities. Detailed follow-up studies would then have to be undertaken to determine specific actions and conditions for revitalizing central cities. This paper, which relies on secondary sources, is designed to provide a basis for further detailed, on-site study.

DEFINITION OF URBAN BLIGHT

Urban blight is a symptom of many complex factors that are at work before blight itself is physically evident. These factors lead to the outflow of people and activities from central cities and result in visible deterioration of physical structures. Some principal characteristics of blighted areas that represent various stages of the appearance of blight as a physical phenomenon are

1. Property values at a low rate or approaching zero (1, p. 11);
2. Replacement of higher-income groups by those with lower incomes (2);
3. A large proportion of abandoned buildings and vacancies (3);
4. Excessive tax delinquency (3);
5. Environmental deterioration, such as noise and air pollution (4); and
6. Concentration of chronic unemployment (4).

CAUSES OF URBAN BLIGHT

The specific causes of blight suggested by the literature may be grouped in several principal classes as follows:

1. Psychological—belief in the profitability of unimproved property (5, p. 12) and the desirability of suburban living (6, p. 48);
2. Social—housing discrimination (7) and rising social standards (8);
3. Economic—a decline in the demand and loss of markets (2), redlining (7), investment tax credits (9, p. 18), and the property tax structure (10);
4. Physical—lax zoning controls (3), deterioration of building stock (11), highway barrier (12), increases in accessibility (13, 14), and traffic noise, vibration, and air pollution (15, p. 157); and
6. Governmental—school desegregation and liberal mortgage lending policies (14).

A macromodel for understanding the development of urban blight in central cities is suggested by Anas and Moses (14). According to the model, business activity leaves the central city in order to avoid high land values and construction costs. This outflow of activity causes the deterioration of public services because disposable tax revenues that had gone into maintaining such services are decreased. The deterioration of public services causes people who are economically capable of relocating outside the central city to do so, which leaves concentrations of the poor. Concentrations of the poor, in turn, increase the demand for unfunded services, which results in revenue imbalances. Revenue imbalances then lead municipal authorities to increase local taxes, which encourages middle-income groups to take advantage of increased accessibility and liberal mortgage terms to move outside the central city.

The operation of the macromodel suggests that a myriad of factors are at work and that each reinforces the next in exacerbating blight.

ROLE OF HIGHWAYS IN URBAN BLIGHT

Traffic congestion on highways produces the negative effects of noise, air pollution, and vibration, which contribute to negative social and psychological conditions. Noise may cause excessive fatigue and intrude on normal conversation. Air pollution, consisting of carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter, may impair psychomotor skills, form photochemical smog, and dirty building facades. Traffic-induced vibration may build up to a degree that is annoying to people and possibly damaging to structures. Traffic congestion contributes to negative social and psychological conditions by discouraging pedestrian activity. People may feel unsafe or dislike walking near a thoroughfare because of noise, litter, and exhaust fumes.

Because of their dependence on walk-in customers, business establishments are particularly susceptible to conditions that discourage pedestrian activities. Elevated highways such as viaducts and bridges may be seen as barriers that people are reluctant to walk under. Poorly lighted underpasses may pose real or imaginary threats to the safety of pedestrians. Highways may be regarded as aesthetically intrusive in a central city in which older building styles or the visual setting (harbors, mountains, skyline) predominates.

These effects of highways produce in the persons or businesses affected a desire to move that is not otherwise present, whereas an additional effect of highways—accessibility—brings to fruition desires to leave the central city that were already felt.

HIGHWAY-RELATED OPPORTUNITIES FOR MITIGATION OF BLIGHT

Since it is recognized that highways will continue to be needed in the central city and that their impact on the central city operates in joint action with other factors, how can planners use highway improvements to mitigate blight?

The application of transportation system management (TSM) and zoning and the provision of joint-development opportunities might mitigate many of the adverse effects of highways on urban areas. TSM, a program sponsored by the U. S. Department of Transportation, is intended partly to enable urban areas to preserve central cities and neighborhoods from the negative effects of traffic. Reducing traffic also removes the blighting influence of congestion.

An example of the use of a TSM measure to reduce blight can be found in Albuquerque, New Mexico (16). Merchants in the city believed that dirty streets and sidewalks and unsafe and expensive parking discouraged downtown shopping. As part of a redevelopment strategy, a segment of the main thoroughfare was converted from a four-lane arterial with parallel parking to a two-lane street with angle parking, and excess traffic was rerouted. The rerouting of traffic, along with other efforts, is expected to arrest blight and encourage the strengthening of the daytime shopping market.

Zoning, as used here, refers to roadside zoning, a type of land use control based on the use of police power. A number of special land use controls could be applied in the context of roadside zoning to mitigate blight: (a) landscaping standards, (b) off-street parking standards for businesses, and (c) building standards for development.

In Charleston, West Virginia, the Triangle Area Renewal Project was amended to provide additional land to buffer the impact of I-77 on an adjacent residential environment (17). The buffering was accomplished by (a) prohibiting residential development within 30 m (100 ft) of the Interstate's right-of-way boundary, (b) permitting only land uses compatible with the highway (e.g., general commercial uses), and (c) requiring landscaping on any land not covered by buildings.

Both TSM and zoning measures are simple and inexpensive to apply. In contrast, joint-development projects may be complex and expensive and often require private financial participation. The advantages of a joint-development project could include (a) financial returns on public investments, (b) direction of physical growth, (c) efficient use of available land, and (d) employment, housing, and other opportunities for residents.

In New Orleans, a joint-development project was planned to reduce blight in the area of I-10—a six-lane, entirely elevated structure (18). Trucks on the road generate a noise level of 90 dB(A) at 15 m (50 ft), and suspended particulate matter exceeds the permissible maximum. With citizen participation, a design team developed an $81 million plan to revitalize the area, including landscaping, a separate turning and stacking lane, plazas under the expressway, relocation of railroad yards, an urban linear park, a municipal office complex, retail stores, and townhouses. To date, the study recommendations and project costs are still being evaluated. It appears that the cost of any joint-development project to reduce blight would be considerable, although federal programs could provide some assistance.

APPLICABLE FEDERAL PROGRAMS

Four federal programs could be used to fund the economic and physical development of central cities:

1. The urban development action grant (UDAG) program of the U.S. Department of Housing and Urban Development (HUD),
2. The urban initiative program of the Urban Mass Transportation Administration (UMTA),
3. The special impact program of the Community Service Administration (CSA), and
4. The public works program of the Economic Development Administration (EDA).

The urban development action grant program was authorized by the Housing and Community Development Act of 1977. Program money is available for projects that encourage joint public-private community development, such as purchasing land, demolishing structures, and developing air rights. UDAG funds have been used to undertake such transportation-related improvements as the construction of pedestrian ways in St. Paul, Minnesota.

The urban initiatives program was authorized under the Urban Mass Transportation Act of 1964, as amended. Transit-related projects that contribute to the revitalization of cities—e.g., intermodal transfer facilities, transit malls, and joint-development projects—are eligible for funding. Funds have been awarded to Fall River, Massachusetts, for the design of an off-street transfer facility and to Atlanta for a bus-only transit mall in the downtown.

The special impact program of CSA was authorized by the Community Services Act of 1974 for the purpose of reducing chronic unemployment and community deterioration. Community development corporations (CDCs) in 40 cities have been established to carry out their self-help efforts in partnership with the business and financial communities. In Rochester, New York, for example, a CDC has received subsidies and technical support from the Xerox Corporation for an electronics venture in the central city.

The public works program was established by the Public Works and Economic Development Act of 1965 to help restore the economic health of areas burdened with high unemployment and low family incomes. Public works program funds have been used in Texarkana, Texas; Toledo, Ohio; and other areas to complement UDAG funds in constructing public service improvements.

Like the above programs, TSM and joint-development efforts of the Federal Highway Administration (FHWA) address the revitalization of central cities, although not with specific authorized funding. Urban areas do have available urban-system funds authorized by the Federal-Aid Highway Act of 1970 to fund TSM measures. More than 70 cities have used these funds to apply automobile-restraint measures, such as closing a downtown shopping street and rerouting traffic, as in Albuquerque, New Mexico, or restricting travel to transit vehicles and pedestrians, as in the Burdick Mall in Kalamazoo, Michigan.

The joint-development efforts of FHWA stem from the Federal-Aid Highway Act of 1961 and Policy and Procedures Memorandum 90-5, the purpose of which was to unify corridor planning and highway design activities in the airspace of the highway right-of-way. Reviews of the effort, however, found joint development difficult to achieve because of such inherent problems as coordination, financing, and legal restrictions (19, p. 38).

FHWA program funds are, however, being used with funds of other federal agencies to strengthen declining urban areas. EDA program funds authorized by the Public Works Capital Development and Investment Act of 1976 are being used to supplement the financing of 38 highway projects, such as the widening of State Street in Los Angeles. FHWA funds are being used in conjunction with UDAG funds in Cambridge, Massachusetts, to construct highway improvements as part of a redevelopment effort.

All four federal programs mentioned above appear to be compatible with each other and with the programs of FHWA. Moreover, the HUD, UMTA, EDA, and CSA programs specifically endorse joint federal agency participation. This combination of programs could be used as leverage to obtain sufficient private money to mitigate blight in central cities and could thereby make possible a comprehensive effort in this area. Since blight has a multiplicity of causes, a comprehensive effort is desirable because of its potential for multifaceted action.

CONCLUSIONS

Preliminary analysis has found that highway transportation constitutes only one of many factors that contribute to the formation of urban blight. In order to succeed, therefore, any effort to reduce blight should address as many causal factors as possible, including social, psychological, economic, and physical ones.

Based on preliminary analysis, three types of mitigative measures appear to have the potential for reducing highway-related blight: (a) TSM, (b) zoning controls, and (c) joint development. The first two are simple and inexpensive to apply. The joint-development alternative is both expensive and complex, and joint funding of projects appears to be a necessary means of making this alternative possible. Participants in a joint funding venture could include private industry, the relevant federal agencies, and state and local governments.

On the federal level, preliminary analysis suggests that a joint effort to mitigate blight could be possible because of the variety of already-existing programs: the urban development action program, the urban initiatives program, the special impact program, and the public works program. Were money available from all of these programs and the programs of FHWA focused on the same project area, revitalization of the central cities could be enhanced.

The conclusions drawn in this paper are preliminary. To determine specific and definitive actions for revitalizing the central cities, it will be necessary to undertake a major field study that would (a) consider the elements of urban environmental design and intergovernmental relations and (b) detail efforts in blight mitigation and their cost-effectiveness. Finally, the study would have to consider policy options and mechanisms for reducing urban blight.

The U.S. Department of Transportation is currently undertaking such a study, called simply the Urban Blight Study. It is expected to be completed in November 1980.

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Generation of Curbside Pickup-and-Delivery Trips

Philip A. Habib and Isaac R. Nehmad

Data collected in a study of the generation of curbside pickup-and-delivery trips in six U.S. cities are presented and analyzed. The generation rates and analysis presented were developed from field data collected in six cities of more than 250 000 population. The study includes data on some 11 000 curbside pickup-and-delivery operations collected at more than 500 generators in the downtown, fringe, and residential sections of the sampled cities. The generation equations presented show that no single independent variable can be consistently used to accurately forecast pickup-and-delivery trips to all land use types. Employment was found to be the most reliable variable for the typical retail or service generator, whereas floor area was found to be best for office buildings. For hotels and residential generators, number of dwelling units was found to be the most reliable variable and, for industrial land uses, a combination of employment and floor area was the best descriptor. Shipment characteristics for the various land uses and conclusions that relate these characteristics to the size of the city in which the generator is located, as well as to other generator attributes, are presented.

The trip-generation rates presented in this paper are developed from field data collected in six U.S. cities of more than 250 000 population. Included are data on some 11 000 curbside pickup-and-delivery (PUD) operations collected at more than 500 establishments in the downtown, fringe, and residential sections of the sampled cities. This paper presents the data-collection methods and the developed demand equations that resulted from the analysis.

SELECTION OF CITIES

The 1970 Census of Population lists 56 cities that have a population of 250 000 or more, among which are six cities that have more than 1 000 000 people: New York, Los Angeles, Chicago, Philadelphia, Detroit, and Houston. The primary concern in selecting the cities to be surveyed in this study was how many other cities could be "represented" by the sampled cities. For this reason, none of the six largest cities were selected as being representative, not even of each other. The attributes of the remaining cities that were considered in the selection process were population, population density, industrialization, proximity to ports, whether the city is part of a "megalopolis", and geographic location.

The population used was that of the city, and the density measurement used was population per square mile (U.S. customary units of measurement were used in the study). Industrialization relates to the percentage of total city employment engaged in manufacturing. Three classes of industrialization were referred to: producing, balanced, and consuming.

The first cut reduced the list of candidate cities to Baltimore, Birmingham, Boston, Cincinnati, Dallas, El Paso, Indianapolis, Louisville, Minneapolis, Nashville, Oklahoma City, Omaha, Phoenix, San Francisco, St. Paul, Tampa, Tucson, and Tulsa. After a more detailed review of parking, goods movement, traffic engineering concerns, survey logistics, and weather considerations, six cities were selected for the survey (see Table 1): Boston, Dallas, Oklahoma City, Phoenix, San Francisco, and St. Paul. San Francisco was selected as the city in which to conduct the pilot study, primarily because of its weather (the study was conducted in early March) and its size.

The survey was predominantly conducted in the downtown areas of each city. However, residential, light industry, and warehousing land uses were surveyed in the fringes as well as outlying residential zones. Data on each pickup or delivery on the study blocks, as well as characteristics of the establishments (land use, size, and employment) and parking regulations and enforcement on each block face, were recorded.

The number and types of generators surveyed in each land use are given below:

Land Use (activity or product)	Number Surveyed	Land Use (activity or product)	Number Surveyed
Bank	10	Liquor	3
Stationery	7	Novelties	5
Clothing	46	Miscellaneous (retail)	22
Department store	5	Shoes	9
Drugstore, health, beauty aids	6	Bar or tavern	9
Electronic	5	Entertainment	3
Fabrics	1	Garage or service station	10
Flowers	2	Hotel	8
Food		Light industry	24
Prepared	47	Office	52
Retail	10	Residential	100
Furniture	3	Service	53
Jewelry	13	Warehousing	11
		Vacant or construction	46

Data on employment and floor area (or number of dwelling units) were collected for each generator.

SURVEY PROCEDURES

The data collection was carried out by locally hired field crews that consisted of college students and/or temporary personnel obtained through employment agencies. A classroom-type training session was followed, where practical, by a dry run on the street under the supervision of study staff personnel.

With the exception of some special generators, each site was observed for a period of five days from Monday through Friday. Daily coverage by the full crew extended from before 8:00 a.m. to after 4:00 p.m. and was dictated by goods-movement activity. Various data-collection forms relating to different needs for the overall project were used. The trip-generation data collected were

1. Generator characteristics—(a) size (gross floor area or units if residential or hotel), (b) employment (except for office buildings and residential), and (c) location [central business district (CBD), fringe, and outlying]; and
2. Trip characteristics—(a) time and date of arrival and departure, (b) type of operation performed (pickup, delivery, or pickup and delivery), (c) parking characteristics, and (d) shipment characteristics.

The data collected on PUD operations in each city are summarized below. These data include about 2000

Table 1. Description of survey cities.

City	Population (000s)	Density	Economic Function	Part of Megalopolis	Port Facilities
Boston	641	High	Balanced	Yes	Yes
Dallas	844	Low	Manufacturing	No	No
Oklahoma City	367	Low	Balanced	No	No
Phoenix	581	Low	Balanced	No	No
San Francisco	716	High	Consuming	Yes	Yes
St. Paul	310	Medium	Manufacturing	Twin Cities	Minor

service calls (repairs or installations) that are not included in the PUD trip-generation data base:

City	Number of Edited PUD Records
San Francisco	3 044
Boston	2 618
Dallas	2 321
Oklahoma City	1 904
Phoenix	1 513
St. Paul	761
Total	12 161

TRIP GENERATION

Previous studies have developed equations for truck trips in urban areas. Since PUD is not entirely a truck-related operation, especially for CBD distribution, many of these studies are not applicable. Variables determined in four related studies on PUD trip generation (1-4) are given below (S = floor area in thousands of square feet, and E = employment):

Study	Type of Activity Area	Daily-Trip-Generation Variable
Marconi (1)	Light industry or warehousing	0.04S
	Retail	0.12S
	Financial (office)	0.12S
Traffic Research Corporation (2)	Manufacturing	0.082E
	Office	0.110E
	Retail	0.278E
Bates (3)	Manufacturing	2.2 + 0.61S
	Warehousing	2.3 + 0.48S
	Office	3.6 + 0.18S
Chatterjee and others (4)	Downtown retail	0.63S, 0.40E
	Wholesale operations	0.55S, 0.50E
	Truck terminal	3.61S, 1.40E

Our study, which obtained data on both employment and floor area, builds on these previous studies to advance the state of the art in PUD trip generation.

It should be noted that the seasonal nature of PUD activity (5) could have resulted in the discrepancies evident in the table above. In this study, data were collected in March in San Francisco, in September in Boston and St. Paul, in October in St. Paul and Oklahoma City, in November in Oklahoma City and Dallas, and in December in Phoenix. The fall period, during which all of the cities except San Francisco were surveyed, is the peak PUD season in downtown areas because of back-to-school activity, fall shopping, Thanksgiving sales, and the imminent Christmas period. Freight movements of consumer products (and studies thereof) are primarily a fall phenomenon in the CBD. Therefore, in order to make the San Francisco data consistent with those for the other five cities, a correction factor of 1.15 (5) was applied to all demand data for that city.

It was felt that the use of a very disaggregated land use structure for the research project would be too cumbersome when it came to possible application of the results in the field. Selected land uses, such as office space, generally stand alone. Other land uses are grouped if they had similar generation and arrival patterns. A PUD trip is defined as a pickup, a delivery, or a pickup-and-delivery trip. Although they are not directly related to demand analysis, the resultant hourly arrival distributions by land use are given below for use in estimating hourly PUD activity:

Time	Arrival Distribution (%) Office	Residential and Hotel	Food	Industry and Warehousing	Retail and Service
6:00-7:00 a.m.	0.1	0.4	2.9	0.2	1.0
7:00-8:00 a.m.	1.4	8.0	7.3	2.4	2.8
8:00-9:00 a.m.	9.6	12.2	11.8	14.0	7.7
9:00-10:00 a.m.	14.4	18.7	19.4	15.4	16.5
10:00-11:00 a.m.	16.6	16.5	19.7	18.1	18.1
11:00-12:00 a.m.	13.4	13.4	15.3	12.4	14.6
12:00-1:00 p.m.	11.0	8.7	7.6	8.6	11.0
1:00-2:00 p.m.	11.4	9.2	7.5	10.8	10.6
2:00-3:00 p.m.	11.9	7.0	4.3	10.0	10.4
3:00-4:00 p.m.	9.9	5.9	4.2	7.4	7.1
4:00-5:00 p.m.	0.3	–	–	0.5	0.2

Office

Office land use is clearly definable as office use in office buildings and does not include other ground-floor uses, such as restaurants and banks. Employment information for office buildings was not obtained because of the decentralized nature of the tenants and because previous studies have shown that PUD demand at office buildings is a function of building size.

Figure 1 shows a plot of weekly generation of PUD trips versus floor area for various land uses. The weekly generation equation for office use is

$$WG = 0.80 \times FA + 2.0 \quad (N = 48, R^2 = 0.93) \tag{1}$$

where WG is average peak weekly generation of PUD trips and FA is floor area (hundreds of square meters).

The distributions of shipment weight and size (number of pieces) at office uses are given in Tables 2 and 3. Mean shipment size was 5.2 packages, and mean shipment weight was 44 kg.

Residential

Single-family dwelling units were predominant among the residential land uses surveyed, but several small and large residential buildings are also represented. Figure 2 shows a plot of weekly PUD trip generation versus number of dwelling units. The resultant weekly generation equation is

$$WG = 0.15 * DU + 2.27 \quad (N = 87, R^2 = 0.94) \tag{2}$$

where DU is the number of dwelling units in the generator.

The distributions of shipment weight and size are given in Tables 2 and 3. The mean shipment weight was 39 kg, and the mean shipment size was 3.8 packages.

Hotels

The downtown areas of the various cities surveyed have both old and new hotels. As hotels grow old, the tenants generally tend to be of the longer-term type and PUD characteristics become similar to those of residential apartment buildings. However, most functioning downtown hotels are an aggregate of rooming and support (restaurants, shops, etc.) functions and are therefore quite dissimilar to residential development. Therefore, the hotel samples shown in this section are functioning hotels, and the "rooming houses" have been grouped with the residential samples.

Figure 2 shows a plot of the weekly generation of PUD operations versus the number of rental units. The resultant demand equation is

$$WG = 0.30 * RU - 12.0 \quad (N = 11, R^2 = 0.96) \tag{3}$$

where RU is the number of rental units in the generator. The negative constant indicates that the equation should only be applied to generators that have more than 100 rooms.

The distributions of shipment weight and size are given in Tables 2 and 3. The average shipment weight was 120 kg, and the average shipment size was 9.1 packages.

The analysis of demand variables presented for land uses in the remainder of this paper uses both floor area and employment. These variables themselves are correlated to varying degrees for specific land uses. Where necessary, single-variable regression equations will be presented.

Figure 1. PUD trips generated per week versus floor area.

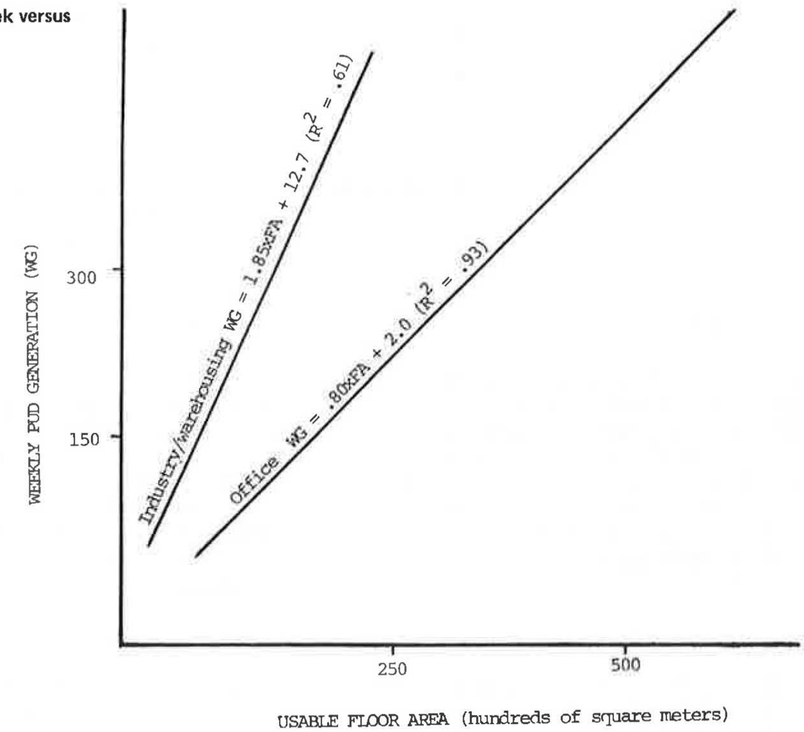


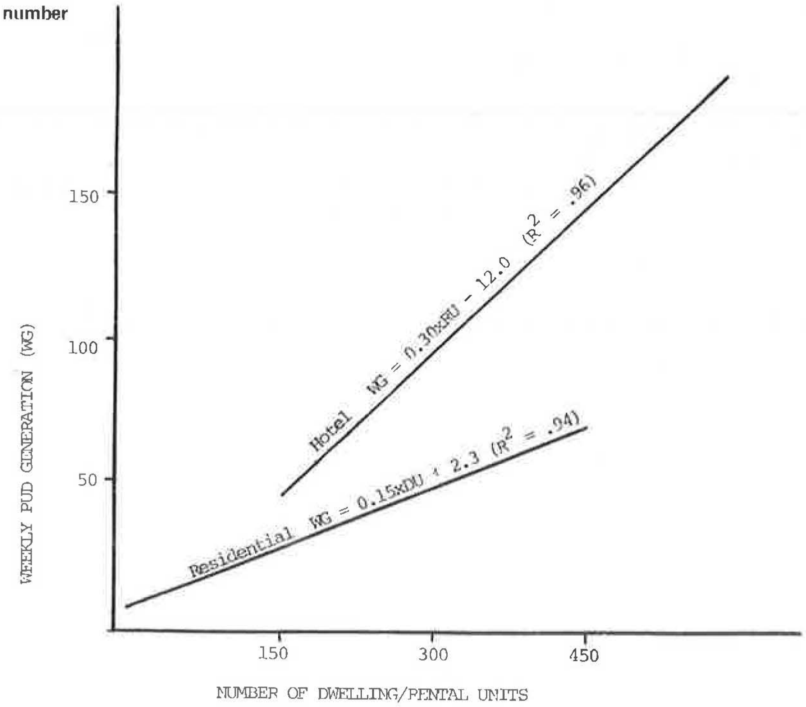
Table 2. Distribution of PUD shipment weights by land use.

Land Use	Distribution by Weight per Shipment (%) <2 kg	2-5 kg	5-25 kg	25-50 kg	50-250 kg	250-500 kg	>500 kg	Avg Weight per Shipment (kg)
Office	29	16	27	11	14	2	1	44
Residential	34	13	34	9	5	2	3	39
Hotel	8	10	24	12	32	7	7	120
Food	6	16	34	16	22	4	2	61
Light industry and warehousing	16	12	21	12	22	7	10	265
Retail and service	22	14	26	13	18	3	4	95

Table 3. Distribution of PUD shipment sizes by land use.

Land Use	Distribution of Shipment Size by Pieces per Shipment (%) <4	4-5	6-10	11-50	>50	Avg No. of Pieces per Shipment	No. of Sample Trips	Avg Weight per Piece (kg)
Office	70	11	10	8	1	5.2	2873	8.5
Residential	79	10	7	4	0	3.8	472	10.3
Hotel	45	13	19	20	3	9.1	535	13.2
Food	51	14	17	16	2	8.0	1098	7.6
Light industry and warehousing	53	12	13	15	7	22.6	1333	11.7
Retail and service	60	12	13	12	3	11.8	3970	8.1

Figure 2. PUD trips generated per week versus number of dwelling (or rental) units.



Retail and Prepared Foods

The foods category of land use is usually omnipresent in downtown areas. It is treated separately because, as mentioned earlier, its demand characteristics by time of day are unique in that a higher percentage of arrivals occur before 9:00 a.m., the time when most other establishments are still closed. The results of the demand analyses indicate that both floor area and employment contribute significantly to R^2. The resultant demand equation is

$$WG = 1.65 \times FA + 1.21 \times E + 5.20 \quad (N = 44, R^2 = 0.25) \tag{4}$$

The employment variable contributes 0.22 to R^2. Figure 3 shows the weekly demand equation, in which employment is used as the only variable.

The demand analysis for food has the lowest R^2 value of all demand equations done for this study, although the equation itself produces results that are reasonable. Loebl's work (6) essentially concluded that a constant value of generation for prepared foods was usable (Loebl's work did not include employment data). For a prepared-food establishment with 10 employees and 1000-m^2 floor area, this research would predict a daily generation of 6.7 PUD trips. Loebl's demand equation would predict a range of 4-6 trips/day.

The shipment characteristics are given in Tables 2 and 3. The weight transferred per trip was 61 kg, and the mean size was 8 packages.

Light Industry and Warehousing

The combination of manufacturing and warehousing was precipitated because (a) only 13 warehousing samples were surveyed in the central areas, (b) several of the manufacturing samples also did some warehousing, and (c) the arrival patterns were quite similar. The weekly generation equation is

$$WG = 1.28 \times FA + 0.31 \times E + 11.96 \quad (N = 31, R^2 = 0.64) \tag{5}$$

The resultant regression equation, if employment only was used as the variable, is shown in Figure 3. Figure 1 shows the demand equation data if floor area was the only variable used. Since floor area and employment are highly correlated for this land use, either of these variables could be used independently with similar accuracy.

The distributions of shipment weight and size are given in Tables 2 and 3. The mean shipment weight was 265 kg, and the mean shipment size was 22.6 packages.

Retail and Service

The retail and service aggregated land use category comprises the following establishment types: bank; stationery; clothing; department store; drugstore, health, and beauty aids; electronic; camera; flowers; furniture; jewelry; liquor; novelties; shoes; bar or tavern; entertainment; garage or service station; service (locksmith, shoe repair); and miscellaneous. They were combined because (a) there were several establishment types for which there were too few samples, (b) the establishment types for which there were large samples all showed similar generation characteristics, and (c) all establishments had similar arrival patterns (primarily because the same carriers service all uses). The weekly generation equation found for the samples is

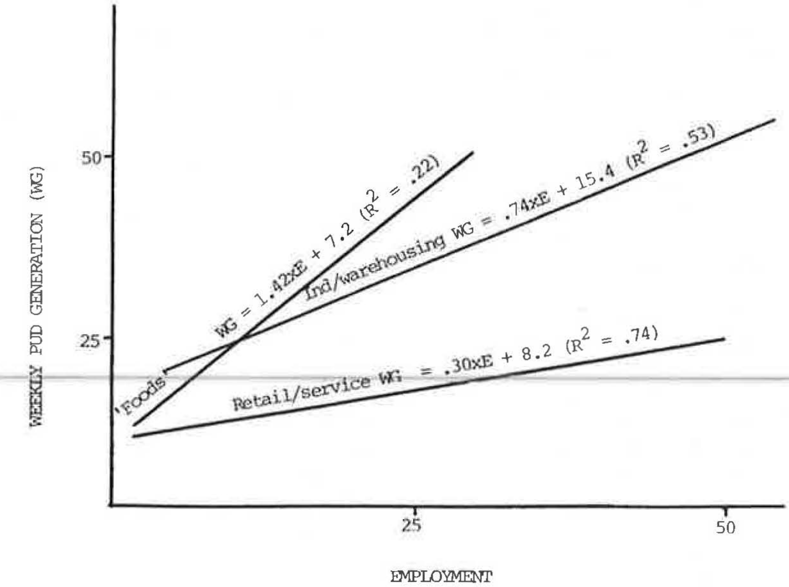
$$WG = 0.024 \times FA + 0.30 \times E + 8.25 \quad (N = 219, R^2 = 0.75) \tag{6}$$

The contribution of R^2 is 99 percent from E and 1 percent from FA. Because of this, it is recommended that the following weekly equation be adopted for use by sacrificing a small amount of accuracy for simplicity. Figure 3 shows a plot of the resultant equation:

$$WG = 0.30 \times E + 8.2 \quad (N = 219, R^2 = 0.74) \tag{7}$$

The distributions of shipment weight and size are given in Tables 2 and 3. The mean shipment weight was 95 kg, and the mean shipment size was 11.8 pieces.

Figure 3. PUD trips generated per week versus employment.



SUMMARY

The data base from which this research was developed is a comprehensive one that encompasses statistics from six cities stratified by size, location, and industrialization. The research could not validate some hypotheses. For example, the research could not substantiate whether demand characteristics vary by city size and location. Another hypothesis was that shipment characteristics within each land use vary by the size of the generator. This was not substantiated within the ranges studied. Therefore, the generation of shipment size and weight for a particular site can be found by using the trip-generation rate and the average shipment characteristics for that land use (Tables 2 and 3).

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Factors That Influence Freight-Facility Location Preference

W. Young, S. G. Ritchie, and K. W. Ogden

An analysis of factors that affect freight-facility location is presented. A multinomial logit formulation is used. Correlation between attributes in the model is minimized by means of a factor analysis. The modeling approach is then shown to be a suitable and potentially valuable approach to analyzing facility location. By using data collected in Melbourne, Australia, the model calibration shows that the decision on facil-

ity location can be modeled by using four attributes of alternative locations: truck transportation, markets, site availability, and labor availability. Of these, the first was the most influential. This result is of value in a transportation planning context because it means that transportation system variables have an effect on the choice of freight-facility location.

In recent years, there has been an increasing awareness of the need to consider goods movement in urban transportation systems planning. As Lay (1) has noted, "The incompatibility of essential and inevitable urban freight movements with the aspirations of urban dwellers ... is surely one of the ... major unsolved problems of urban transportation." It is now realized, for example, not only that commercial vehicles form a distinct and significant proportion of all vehicles in the traffic stream but also that a substantial proportion (perhaps 50 percent) of total urban transportation costs is attributable to freight transportation (2). Furthermore, both passenger and freight transportation systems have important spatial ramifications. Transportation effects, for instance, often influence the location decisions and the viability of industry (3-5). However, the extent of this influence and the nature of the relationship are as yet generally not well understood.

Although the amount of urban land occupied by freight-distribution facilities is relatively small, such land uses are among the most volatile from a community viewpoint (especially where large, heavy trucks are involved). Data from the United Kingdom (6) have shown that freight depots and warehouses in London are highly footloose. If this is so in other cities (and Australian cities in particular), it may be possible to influence the location of such freight-generating land uses through the planning process to reduce transportation costs and broader community costs associated with environmental and social impacts. In fact, Ogden (7) has suggested that control of the location of freight-generating activities is one of the main influences that the planner can exert on the urban freight system.

However, although a large body of theoretical and empirical work on the location of manufacturing (i.e., secondary) industry already exists, comparatively little has been reported on the location of freight-distribution activities, which mostly fall within the tertiary or service-industry sector. Consequently, the level of understanding of the location behavior of firms that operate such facilities, and the extent to which their choice processes might be common, is quite limited. Thus, before we even attempt to make predictions about the spatial impact of policy initiatives on urban goods movement, it is essential to investigate further the location characteristics of such freight firms. The successful derivation of an explanatory capability for the location preference of individual freight firms would ultimately lead to the development of disaggregate behavioral models of freight-facility location for use in transportation and land use planning of urban systems (8).

This paper reports some results of a study of the locational preferences of firms that operate freight facilities in Melbourne, Australia (9). The study included a range of firms whose main function was the distribution of goods, including freight forwarders, trucking firms, wholesalers, and distributors. Some firms whose main function was not transportation or distribution but that had a significant distribution function were also included (e.g., oil companies and major retailers). Freight terminals, depots, storage facilities, distribution centers, warehouses, and similar facilities were included in the study.

UTILITY MODEL OF LOCATION CHOICE

In order to analyze the effect of transportation and land use policy decisions on the location of freight facilities, a model sensitive to the influence of such policy decisions was used. The model was based on the random utility approach (10), which assumes that a firm will select the location from which it receives the maximum utility. Hence, in a choice between locating a freight facility in area A or area B, area A will be preferred if

$$U_k^A > U_k^B \tag{1}$$

where U_k^j = utility of area j to firm k.

If it is assumed that utility is a function of the satisfaction obtained from each characteristic of the location (11), and if an assumption of additive utilities is used, then area A will be preferred if

$$\sum_{i=1}^{n} U_{i,k}^A > \sum_{i=1}^{n} U_{i,k}^B \tag{2}$$

where $U_{i,k}^j$ = utility of characteristic i for area j to firm k, and n = number of characteristics. For each characteristic, the utility is composed of two independent elements. These are the degree of importance the firm associates with each location characteristic and the degree of satisfaction that firm perceives for each characteristic, for the particular location in question.

Thus, the utility of each characteristic can be expressed as

$$U_{i,k}^j = I_{i,k} \cdot S_{i,k}^j \tag{3}$$

where $I_{i,k}$ = the importance of characteristic i to firm k and $S_{i,k}^j$ = the satisfaction with characteristic i in area j as perceived by firm k. Substitution of Equation 3 into Equation 2 gives the result that area A will be preferred to area B if

$$\sum_{i=1}^{n} I_{i,k} \cdot S_{i,k}^A > \sum_{i=1}^{n} I_{i,k} \cdot S_{i,k}^B \tag{4}$$

Noting that the importance associated with each characteristic is independent of the particular location, we derive the following expression:

$$D_k = \sum_{i=1}^{n} I_{i,k}(S_{i,k}^A - S_{i,k}^B) \tag{5}$$

If $D_k > 0$, area A is preferred; if $D_k < 0$, area B is preferred; if $D_k = 0$, the firm is indifferent with respect to location. At this stage, the model is expressed deterministically. That is, if $D_k > 0$, area A will always be preferred. In real life, however, this is not always the case. There will always be errors or omissions in the list of characteristics and, given the same level of service for one characteristic, the levels of satisfaction perceived by different firms may be different.

Therefore, in expressing the utility of an area to an individual firm, there should also be a random component in the utility. Thus, the utility of an area (Equation 3) can be more fully expressed as

$$U_{ik} = \sum_{i=1}^{n} I_{i,k} S_{i,k}^j + e_k^j \tag{6}$$

where e_k^j = error term in the utility perception of area j for firm k. Substituting in Equation 5 gives

$$D_k = \sum_{i=1}^{n} I_{i,k}(S_{i,k}^A - S_{i,k}^B) + (e_k^A - e_k^B) \quad (7)$$

or

$$p_k(A,B) = \phi\left[\sum_{i=1}^{n} I_{i,k}(S_{i,k}^A - S_{i,k}^B)\right] \quad (8)$$

where $p_k(A, B)$ = probability of firm k choosing area A in a choice between areas A and B and ϕ = cumulative distribution function of $(e_k^A - e_k^B)$.

If at this point it is assumed that e_k^A and e_k^B are independently and identically distributed with the Weibull distribution, then Equation 8 results in a logit model (12):

$$p(A,B) = 1/\{1 + \exp[-(U^A - U^B)]\} \quad (9)$$

The above derivation has dealt with the binary-choice situation only. In many cases, more than two alternatives exist. Fortunately, the above model is capable of extension to a choice situation that involves more than two alternatives. For the logit model, Luce and Suppes (13) have extended the above theory to form the multinomial logit model:

$$p_k(A) = e^{U^A} \Big/ \sum_{j=1}^{L} e^{U^j} \quad (10)$$

where L = number of alternatives and $p_k(A)$ = probability of choosing alternative A.

EMPIRICAL STUDY

Although the choice model outlined above has been applied to residential location choice (14, 15), it has not previously been applied to the location preference of firms and, more particularly, to firms involved in the distribution of freight. Accordingly, to the extent that the empirical study reported in this paper breaks new ground, the research must be considered exploratory and one of its major objectives to be to provide and stimulate directions for future research.

Sample Selection

In selecting a sample from which to obtain data for the building of location choice models, two criteria should be met. The first is that the sample should be homogeneous with respect to location choice. This criterion was partly met in this study by selecting only firms that were (a) involved in the distribution of freight and (b) located in Melbourne. However, since the distribution sector is large, different firms have different market and location characteristics and therefore the sample could not be said to be truly homogeneous.

The second criterion is that the firms should be in equilibrium so that the factors that affect the decision to locate will be the same for all firms in the study. It is unlikely that this criterion will be satisfied, since different firms in the sample had been at their present location for different lengths of time and each firm was probably faced with a unique set of characteristics when it made its latest location decision. However, after that decision was made, changes in the firm's circumstances, or in the urban and economic environment, may have resulted in another location being more appropriate. To overcome this problem of lack of equilibrium, respondents to the survey were asked to compare their existing location with one other possible location, as of the time of the study and not as of the time when their last location decision was made. They were also asked which of these two locations they would select if they were making their location decision now. This preferred location, rather than the firm's actual current location, was used in the development of the models presented in this paper.

It is important at this point to note the distinction between the preferences of a decision-making unit and its final decision since, even if it is assumed that a firm's location behavior is rational and that the choice set for the firm is completely specified, a firm's preference for a location other than its current one need not necessarily lead to a relocation. The preferences of individual firms for alternative locations can be viewed as a measure of the demand for alternative locations but, before a choice decision will result, the supply side of the equation and, more specifically, the interaction of demand and supply must be considered. Moreover, unless the perceived "benefit" to the firm in moving to an alternative location exceeds the cost of that move, perhaps by some threshold amount, the firm is unlikely to relocate regardless of its stated preferences.

Questionnaire

To apply the model outlined earlier in this paper, data on importances and satisfactions are required. In this study, these data were obtained by using a questionnaire completed during interviews with senior management personnel of a sample of firms in Melbourne (16). These firms covered a range of activities in the transportation and distribution sector. A total of 71 questionnaires were obtained in this way.

More specifically, each respondent was first asked to rate on a semantic scale, whose end points were 1 and 100, how satisfactory two locations were with respect to 19 location characteristics. The two locations were the firm's current location and one other possible location nominated by the respondent. (Note that all areas in the urban region can be considered alternative locations. For example, land use planning regulations may prohibit freight activities in certain localities. Thus, if all locations were considered in calibrating the model, a biased result might be obtained. This study only included one alternative, selected by the respondent, to ensure that the alternatives considered were valid for that firm.)

The 19 location characteristics were as follows: closeness to existing customers, closeness to expanding markets, closeness to other facilities operated by the firm, closeness to arterial roads, closeness to freeways, access to country highways, closeness to rail freight facilities, closeness to port facilities, closeness to public transportation, traffic congestion and delay, availability of suitable sites, investment potential, company prestige, cost of land and buildings, cost of council rates (land taxes), cost of operating the respondent's vehicle fleet, availability of labor, and environmental impact of the respondent's facility.

Respondents were then asked to rank, on a similar semantic scale, how important each of these characteristics would be in their selection of a location for their freight facility. Finally, they were asked to rate both location alternatives overall. It is interesting to note that, although most respondents ranked their existing site higher, many did not.

The result of this part of the questionnaire was a set of data on satisfactions and importances for each of the 19 characteristics given above. From these, it was pos-

Table 1. Location characteristics included in prime factors determined by factor analysis.

Factor	Variance Explained (%)	Characteristics Included in Factor	Variance (%) In Factor	Variance (%) In Other Factors	Factor Loading
Truck transportation	27.6	Firms	36	9	0.60
		Roads	55	1	0.74
		Freeways	20	2	0.45
		Operating costs	36	10	0.60
Rail and public transportation	13.3	Railways	16	3	0.40
		Public transportation	96	4	0.95
Markets	12.8	Customers	66	21	0.81
		New markets	46	2	0.65
		Facilities	24	1	0.48
Site cost	11.2	Land cost	74	1	0.86
		Council rates	18	0	0.42

sible, by using the above theory, to build a model of facility location preference.

ATTRIBUTE FORMATION BY FACTOR ANALYSIS

Before the formulation of the model of facility location preference is explained, it is necessary to explain how the data obtained in the questionnaire survey were made suitable for analysis.

The characteristics introduced into the process of model calibration were in the form of differences in the utility gained from each characteristic (Equation 4), the preferred location being taken first. However, the characteristics described above are by no means unique or mutually exclusive and so may be interrelated. For example, several of the characteristics given above relate to closeness to transportation, whereas perhaps only one relates to the availability of labor. Since correlations between independent variables can lead to a spurious model, it was necessary to determine which, if any, of the characteristics were correlated and to combine those that were into a single factor. To do this, a factor-analysis technique, which measures the latent dimensions present in the data set, was used (17, 18).

It is first assumed that many of the characteristics in the data set can be combined linearly to represent the general factors that are being sought. This linear relation is determined by measuring the correlation between each of the characteristics. The principal components are determined from these correlations. These principal components are then "rotated" until the first component explains the maximum possible variance in the data. The second component is then the one that explains the second largest amount of variance and is also at right angles to (i.e., uncorrelated with) the first component. The process continues until all of the variance is explained. The amount of variance explained by each factor can be represented by the eigenvalue (19).

Since each of the components explains progressively less of the total variance, there comes a point at which a factor explains less of the variance than a single characteristic. This point is reached when the eigenvalue of the factor is less than 1.0. Therefore, only components that had eigenvalues greater than 1.0 were used in this study.

The procedure used to isolate the factors was iterative in nature. The factor analysis was carried out on all of the characteristics, and factors whose eigenvalues were greater than 1.0 were then used as the underlying dimensions of the data set. All characteristics that were not highly correlated with these factors were then set aside from the analysis. This procedure was repeated until all remaining characteristics were highly correlated with one of the factors.

The factor analysis showed that 11 of the 19 characteristics could be replaced by four prime factors, those for (a) truck transportation, (b) rail and public transportation, (c) markets, and (d) site cost.

Table 1 summarizes the features of these four factors. The individual characteristics that constitute each of the four factors are given, together with (a) the percentage of the variance in that characteristic explained by the factor and (b) the percentage of the variance in that characteristic explained by the other three factors. The fact that a was much greater than b in each case indicates that the factor analysis was indeed associating each characteristic with a closely related factor.

The percentage of the total variance in all characteristics included in the factor analysis is also given. It can be seen that the truck-transportation factor "explained" the highest proportion of the variance in the characteristic set. But, as will be discussed later, this result does not necessarily mean that this explains the greatest amount of variance in the respondent's preferences.

The factor loading given in Table 1 is the square root of the proportion of the variance in that characteristic explained by the factor (17). This was used in the calculation of factor scores, as follows:

$$F_{kq} = \sum_{j \epsilon S_F^k} (x_{kj})[a_{kq}/(1/\lambda_q)] + n_q \tag{11}$$

where

F_{kq} = factor scores for factor q for firm k,
S_F^k = set of characteristics forming factor F_{kq},
x_{kj} = characteristic values for firm k and characteristic j,
a_{kq} = factor loadings for firm k for factor q,
λ_q = eigenvalue corresponding to factor q, and
n_q = error introduced by neglecting variables that have a_{kq} values not significantly different from zero.

These factor scores substitute for the values of the individual characteristics included in each factor (as discussed below).

As noted previously, when the factor analysis reached a point at which a particular factor explained less of the variance than an individual characteristic, there was no point in combining individual characteristics to form new factors. Thus, the characteristics that were not absorbed into factors by that stage remained as separate characteristics not correlated with any factor. These characteristics were (a) highways, (b) port, (c) congestion, (d) site availability, (e) investment, (f) prestige, (g) labor availability, and (h) environment.

Thus, in building a location model, both factors (Table 1) and uncorrelated characteristics (as listed above) were incorporated as independent variables. These two types of variables are referred to as attributes, and the resulting model may be termed an attribute model.

THE MODEL

The theory outlined earlier states that a location preference is a function of the utility difference between alternative locations. The utility difference in turn is a function of a number of relatively uncorrelated attributes, as just defined. Thus, the total utility difference that firm k perceives, in comparing locations i and ℓ, is represented by

$$dU_k^{i\ell} = \sum_{j\epsilon\gamma^k} b_j^{i\ell} Y_{kj}^{i\ell} + \sum_{q\epsilon\theta^k} c_q^{i\ell} F_{kq}^{i\ell} + \epsilon_q \qquad (12)$$

where

$b_j^{i\ell}$ = weighting given to unfactorable characteristic j,
$Y_{kj}^{i\ell}$ = characteristic value for characteristic j by firm k,
γ^k = set of unfactorable characteristics for firm k,
$c_q^{i\ell}$ = weighting given to factor q,
$F_{kq}^{i\ell}$ = factor score for factor q for firm k,
θ^k = set of factors for firm k, and
ϵ_q = error function for factor q.

Calibration of the model involved determination of the b and c coefficients above. The model was initially calibrated by using all 12 attributes—the four factors in Table 1 and the eight uncorrelated characteristics. The resulting model is described by the data given below ($-2 \log \lambda = 56.5$; percentage correctly predicted = 85 percent):

Attribute	Coefficient (10^{-3})	Standard Error of Coefficient (10^{-3})	T-Statistic
Truck transportation	1.009	0.574	1.76
Rail and public transportation	0.091	0.385	0.23
Markets	0.763	0.401	1.90
Site costs	0.130	0.296	0.44
Highways	0.189	0.389	0.49
Port	0.079	0.292	0.27
Congestion	−0.987	0.419	−0.24
Site availability	0.299	0.203	1.47
Investment	−0.055	0.233	−0.24
Prestige	−0.120	0.325	−0.37
Labor availability	0.628	0.466	1.35
Environment	0.079	0.297	0.26

It can be seen that many of the coefficients were not significantly different from zero, which implies that a model with fewer than 12 attributes could suffice.

The progressive elimination of attributes that had coefficients not significant at the 90 percent level eventually produced a model with only four attributes: truck-transportation factor, markets factor, site-availability characteristic, and labor characteristic. The results of the calibration of the model that incorporated these four attributes are given below ($-2 \log \lambda = 58.0$; percentage correctly predicted = 86 percent):

Attribute	Coefficient (10^{-3})	Standard Error of Coefficient (10^{-3})	T-Statistic
Truck transportation	1.01	0.39	2.61
Markets	0.73	0.32	2.26
Site availability	0.30	0.14	2.24
Labor availability	0.59	0.37	1.58

It can be seen that the standard error of the estimate was generally only a small proportion of the value of each coefficient, which indicates the robustness of the model. As explained earlier, the prediction of location preference was not based on firms' actual location but on their stated preferred location, which in some cases was the alternative site.

The second of the two tables above also provides an indication of the significance of the model as a whole. The likelihood ratio statistic ($-2 \log \lambda$), where $\lambda = [L(0)/L(\hat{\theta})]$, shows that this model, with its four degrees of freedom, is significant at the 95 percent level (20).

The four attributes that appeared in the model to be the most significant cover the sorts of considerations that, intuitively, would be expected.

The truck-transportation attribute included not only proximity to arterial roads and freeways but also truck operating cost and closeness to firms that provide services (e.g., spare parts, fuel, and financial services). However, closeness to nonhighway transportation facilities, such as a port or a rail terminal, was not included in this attribute.

The markets attribute included proximity to both existing and future markets and also to other facilities operated by the same firm. In the interviews, several respondents pointed to the advantages and operational flexibility of having all their firm's Melbourne activities together. Similarly, many firms had only relatively few clients or a specialized segment of the market and mentioned the obvious advantages of locating near their clients.

The site-availability attribute referred to the availability of a suitable site in the area concerned. Many firms nominated as their alternative location an inner-suburban or near-central locality (reasons for this, in the Melbourne context, included proximity to rail yards for firms that serve these markets, accessibility to radial freeways and arterial roads, and the cost advantages of having trucks running in the counter-peak direction). Since few suitable sites exist, this attribute figured quite prominently as a governing factor in location choice.

Finally, the labor-availability attribute was significant. Although much of the labor used in the freight and distribution sector is relatively unskilled, respondents would apparently consider the availability of suitable labor an important factor in their location choice.

Of the attributes eliminated from the model (rail and public transportation, site costs, highways, port, congestion, investment, prestige, and environment), none had a significance level greater than 70 percent.

The lack of significance of public transportation results from the dominance of the automobile as a means of transportation to and from work in locations outside the Melbourne central business district. For site costs, it may be that, as in the choice of residential location (21), the cost of the site acts as a constraint and therefore serves to restrict the choice set open to the decision maker rather than being an element of the utility function. Alternatively, the cost of the site may be a secondary consideration alongside such variables as truck operating costs and site availability and, if a suitable site were to become available in the preferred locality, its price would not (within reason) be a prime factor.

The three transportation-related characteristics that were excluded (highways, port, and congestion) apparently figured less than the transportation-related variables that were included. Perhaps the fact that only a minority of the sample was engaged in either country or interstate work or on port-related work explains the low significance of the highway and port variables. A much larger sample that would enable separate models to be developed for different market segments would be needed to check this.

The investment potential of the property and the prestige gained from a particular location appeared to be relatively unimportant in the freight and distribution sector; this contrasts with office location, in which these attributes may be quite important (22).

The environmental impact tended not to be an important factor in its own right, possibly because an individual firm had little control over it. The various environmental protection laws have to be complied with but, once that is done, these factors cease to be important. For this reason, it may be that environmental considerations are reflected in the land costs.

ELASTICITIES

Although the model includes only those attributes with coefficients that are significant at the 90 percent level, it does not indicate which of the four attributes has the most influence. To do this, it is necessary to develop elasticities of the preference probabilities with respect to each of the attributes. The direct elasticity for the multinomial logit formulation is expressed as follows (23):

$$E_{Z_{mi}} = d_m Z_{m\ell}(1 - P_{i\ell}) \tag{13}$$

where

$E_{Z_{mi}}$ = direct elasticity with respect to Z_{mi},
d_m = coefficient of Z_m,
$Z_{m\ell}$ = utility of m th explanatory attribute for alternative area ℓ, and
$P_{i\ell}$ = probability of preferring area i to area ℓ.

The results are summarized below:

Attribute	Attribute Mean	Direct Elasticity (p = 0.87)
Transportation	4720	0.62
Markets	3788	0.36
Site availability	3850	0.15
Labor availability	4485	0.34

The mean value of the attribute utility given above is calculated from

$$Z_{m\ell} = \text{attribute mean} = \sum_{k\epsilon\alpha^j} I_{kj}(S^{\ell}_{kj})/N \tag{14}$$

where

α^j = set of firms rating attribute j,
I_{kj} = importance placed on attribute j by firm k,
S^{ℓ}_{kj} = satisfaction gained from attribute j by firm k if located in area ℓ, and
N = total number of firms rating attribute j.

The direct elasticities, calculated from Equation 13, at the mean value of each attribute are also given in the table above for the probability of choice associated with the average respondent (with the logit model, because elasticity varies with the probability p of a firm choosing location i, the elasticities can only be expressed for a given value of p). The interpretation to be put on the values of elasticities given in the table is that they show how the model output changes if one attribute is varied. At any value of p, the higher the value of the elasticity for any attribute, the more sensitive is the location choice to changes in the value of that attribute. For example, the table above shows that, for a 1 percent increase in the respondent's perception of, say, the truck-transportation attribute for area i, there will on average be a 0.62 percent increase in the probability of preference for area i.

The table indicates that the truck-transportation attribute had by far the most influence. Access to labor and the market attribute had a lower elasticity but were still found to have some influence on the location decision. Availability of suitable sites was the attribute least sensitive to change.

This result is important in a transportation planning context because the truck-transportation attribute (which includes closeness to arterial roads and freeways as well as vehicle operating costs and closeness to other facilities operated by the firm) is one that is partly under the control of the public sector. Thus, by influencing the perception of this attribute, there is some scope for the planner to have an influence on the location of freight facilities.

DATA LIMITATION AND IMPLICATIONS

The research outlined in this paper involves the application of an existing choice model to the location preferences of freight firms. Since the study is exploratory in nature, it is important to highlight some of the biases that may be present in the approach and to suggest ways of avoiding them in the future.

One possible bias results from the fact that the respondent was required to rate only two locations. In reality, it is more likely that a firm would consider several alternatives in its choice of a location. If the two locations considered in this study are not representative of all of the alternatives that would be considered by the decision maker, it is likely that a derived model will reflect this bias. One way of overcoming this problem is to incorporate a wider range of alternatives in the survey method.

A second bias results from the hierarchical nature of choice processes (21). Since it is impossible for firms to consider all sites in an urban area in making a location decision, it is likely that they would reduce the number of alternatives to a workable number. The process of reducing the choice set may result in the decision maker looking at a group of alternatives that are very biased spatially. Any model built on this subgroup of alternatives is only valid for the final location choice and thus overlooks the initial choice-set decision. Attempts to overcome this bias can only be made if the entire location-choice process is investigated.

Finally, the point that was mentioned earlier in relation to the linkage between preference and choice should be emphasized. The model and the assumptions inherent in its construction apply to the respondents' preferences for particular locations. In fact, physical, institutional, and social constraints may prohibit a firm from choosing the preferred location. It may, in fact, choose a suboptimal location. Therefore, more detailed knowledge about the process linking preference and behavior is necessary before the model can be applied with confidence.

CONCLUSIONS

This paper presents an analysis of factors that affect freight-facility location preference by using a multinomial logit model formulation. Because of the exploratory nature of the study and the relatively small sample size involved, the results can only be taken as preliminary.

This qualification notwithstanding, the results are encouraging. It appears that the factor-analysis technique used to minimize the correlation between attributes in the model was successful, and the modeling approach itself appears to be a suitable and potentially valuable approach to analyzing facility location preference.

The results of the model are also interesting and valuable. For the Melbourne data, the location decision can be modeled by using four attributes of the alternative locations: truck transportation, markets, site availability, and labor availability. Of these, the truck-transportation attribute was by far the most influential. This result is of value in a transportation planning context because it means that, by varying the transportation system and by influencing perceptions of the transportation attribute, the planner is able to have some influence on the location of freight facilities in urban areas.

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Truck Sizes and Weights: A Scenario Analysis

C. Michael Walton and Dock Burke

The findings of a current study in the state of Texas to evaluate some of the effects of allowing larger and heavier trucks to operate on the highway system are presented. Four scenarios, each of which includes four to six vehicle classes, were studied to determine the effects each would have on highway bridge costs, truck operating costs, and fuel consumption over a 20-year planning period. One scenario represents the existing legal situation, and the other three range from a weight-only increase to variations in size and weight. City streets and county roads are not included in the analysis. One scenario that includes eastern-region double-trailer and triple-trailer combinations compares favorably with the current situation in terms of estimated highway costs. This scenario is characterized by truck units that have a maximum length of 32 m (105 ft), maximum width of 2.59 m (102 in), and gross vehicle weight (axle) of 468.9 kN (105 500 lbf) and retains the current bridge formula. A maximum truck unit height of 4.11 m (13.5 ft) is also retained. Savings in truck operating costs and fuel consumption are estimated to be significant. The full results for each scenario and highway class are given. The highway costs used in the analysis reflect costs related to pavements and bridges; they do not include any consideration of changes in geometric design conditions or costs associated with public safety.

Certain issues surrounding legal limits on the size and weight of vehicles have become a primary policy concern of government and the freight industry. Such concern is reflected by current federal initiatives (stemming from the Surface Transportation Act of 1978), related study activities, and actions of several state transportation agencies.

Fuel shortages and rapidly increasing fuel prices have provided an impetus for resolving many of the problems associated with vehicle sizes and weights. The underlying idea is frequently reflected in a simple relationship: Larger vehicles can carry more freight per unit of fuel. Fuel savings then becomes a measure of effectiveness by which to evaluate changes that will permit larger vehicles.

Although fuel conservation is important, however, it is only one of many measures that can be used in an analysis of the size and weight issues. We must not be misled into the widespread use of a "fuel theory of value" in which energy considerations are exclusively important. Even though the fuel-conservation aspect is of current interest, traditional dollar costs and dollar savings provide a clearer and more comprehensive measure of the effects of changes in vehicle sizes and weights.

In Texas, a study is under way to evaluate some of the effects of operating larger and heavier vehicles on the highway system. Initial results, obtained by using a study technique modified from NCHRP Report 141 (1), have shown estimated pavement costs, bridge costs, savings in truck operating costs, and fuel savings that would result from increases in limits on axle weight and gross vehicle weight. The work reported in this paper extends the previous analysis and allows for increases in vehicle length and width as well as in weight (2).

PREVIOUS TEXAS STUDY

In 1978, a study was undertaken to assess the effects of projected truck traffic on the Texas highway system. The study included the evaluation of costs and benefits for a 20-year planning horizon. Alternative scenarios of future truck traffic were assessed. The study did not consider the effects of changes in the size of trucks, only an increase in gross vehicle weight (GVW) and axle load. The effects of heavy trucks on county roads and city streets were not analyzed.

The study was organized into three phases:

1. Current and future truck-traffic distributions were established for each of two scenarios. Scenario A was evaluated as the conditions that would develop under the present weight laws. Scenario B was evaluated as the conditions that would develop under a possible future legal increase in weight limits.
2. The comparative costs required to maintain the state highway system in an acceptable condition while carrying the traffic estimated for both scenarios were evaluated.
3. The incremental benefits associated with the variation in conditions between scenarios A and B were evaluated, and these benefits were associated with the increased payloads of scenario B over scenario A.

The major approach in the 1978 study involved estimating the comparative maintenance and rehabilitation costs of maintaining the state highway system under current weight limitations and under different, future weight conditions. The incremental costs for scenarios A and B associated with heavier truck loads and the corresponding savings in truck operating and fuel costs for the 20-year period were computed for three highway classes. It was determined that, if changes in weight laws are undertaken, further analysis would be needed to select those routes that would carry relatively large freight tonnages and would cost relatively less to upgrade.

CURRENT APPROACH

The maximum weight of trucks on highways is currently limited by size and weight laws. Trucks that carry high-density commodities are limited by axle weight and GVW; trucks that carry low-density commodities are limited by the capacity (size) of the truck. Increased size and weight limits can increase truck capacity in at least three ways:

1. Retain the existing limit on size and increase the limit on axle weight and GVW,
2. Retain the limit on axle weight and increase the limit on size and GVW, or
3. Increase the limits on size, axle weight, and GVW.

These three measures will reduce energy consumption and truck operating costs, but they will also have an impact on the cost of highway rehabilitation, bridge cost, highway safety, highway geometric requirements, and the highway environment in general. The benefits of each measure must be valued against its cost.

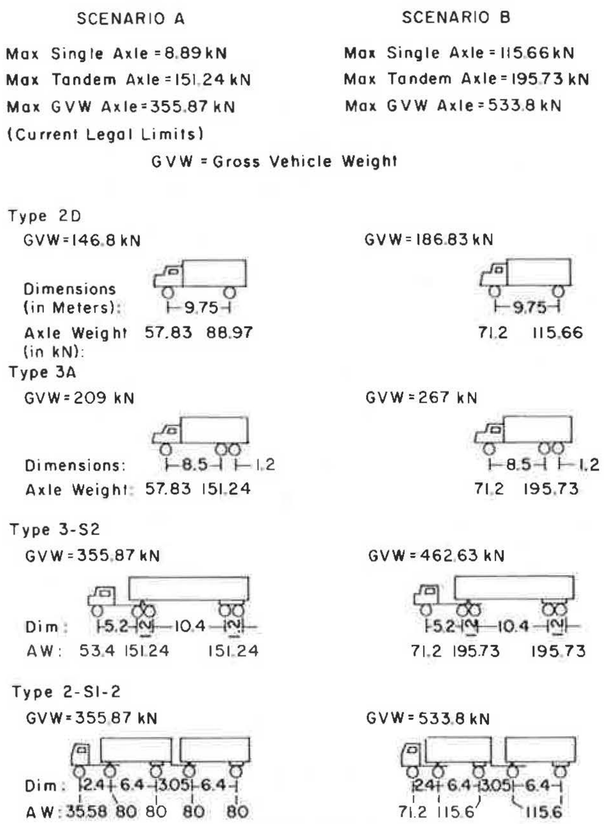
Most highways are designed to withstand a specific number of 80-kN [18 000-lbf (18-kip)] single-axle-load repetitions. The passage of a 62.22-kN (14 000-lbf)

Table 1. Weight and length limits by scenario.

Scenario	Maximum Axle Load (kN) Single Axle	Tandem Axle	Maximum GVW (kN) 1[a] (kN)	2[b] (kN)	Length (m)	Operations of Doubles and Triples
A	88.89	151.11	355.55		19.81	NP
B	160.00	195.55	533.33		19.81	NP
C	88.89	151.11	355.55	468.88	32.00	All highway classes
D	88.89	151.11	355.55	BF	32.00	All highway classes

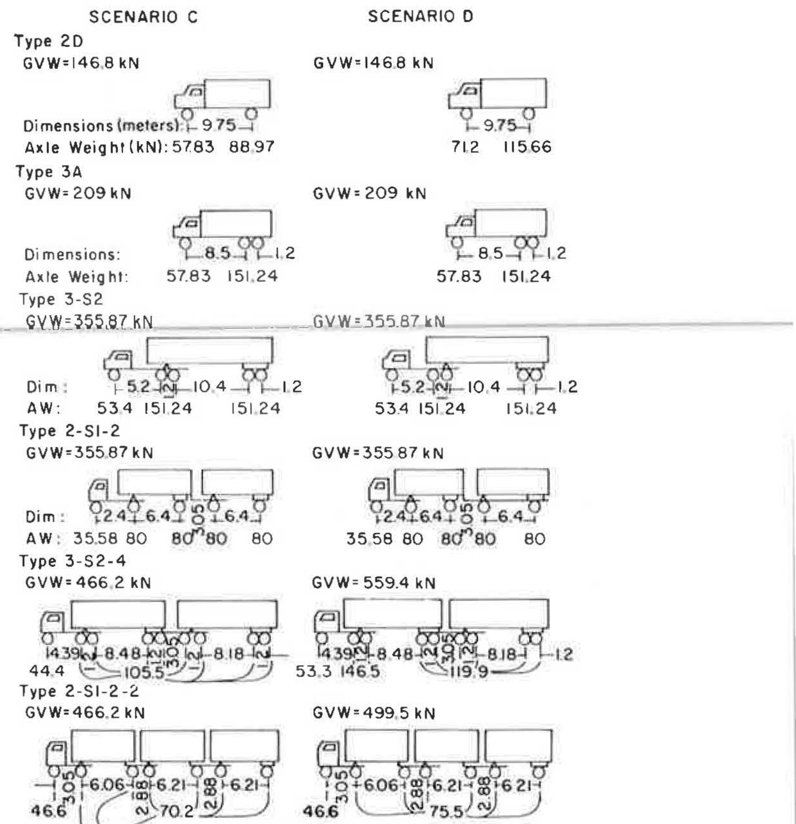
Note: 1 kN = 224.8 lbf; 1 m = 3.28 ft.
NP = not permitted; BF = bridge formula governs.
[a]For vehicles and combinations 19.81 m or shorter.
[b]For eastern region double- and triple-trailer combinations.

Figure 1. Selected truck configurations for scenarios A and B.



NOTE: 1 kN = 224.8 lbf, 1 m = 3.3 ft

Figure 2. Selected truck configurations for scenarios C and D.



NOTE: 1 kN = 224.8 lbf, 1 m = 3.3 ft

axle is equivalent to the passage of 0.34 80-kN single-axle load—about one-third the effect of an 80-kN axle load. The effect of axle load on pavement increases at a much faster rate than the corresponding increase in axle weight itself. A 97.77-kN (22 000-lbf) axle load is equivalent to 2.37 80-kN single-axle loads. Thus, the increase in axle weight will increase pavement damage and shorten pavement service life (3).

Changes in size and weight limits also affect bridges. Large trucks affect the geometric capacity of the bridge, particularly in vertical and horizontal clearance.

Changes in truck size can significantly affect highway geometric requirements. For example, longer and wider vehicles can increase the design standards for highway geometrics. A number of studies on the effects of various elements of vehicle size on highway geometrics have been initiated.

Highway safety is another major issue that must be considered. The operational safety of larger and heavier trucks on highways has been a very controversial issue. More research and data are needed for a better understanding of the issue (4). Research is also needed on the impact of larger and heavier trucks on noise, visual quality, and air pollution.

The Center for Transportation Research at the University of Texas at Austin, the Texas Transportation Institute at Texas A&M University, and the Texas State Department of Highways and Public Transportation (SDHPT) have developed a set of scenarios for use in evaluating the benefits and costs of increasing truck size and weight. Table 1 gives a brief summary of the four scenarios.

Scenario A represents the existing law and limits. Scenario B is a weight scenario in which axle weight and GVW limits increase but size does not. Scenarios C and D integrate size and weight options. Truck width is allowed to increase to 2.59 m (102 in) and truck length to 32 m (105 ft) maximum; height limits are restricted to the existing limit of 4.14 m (13.5 ft). Scenarios C and D differ only in axle weight and GVW for the double- and triple-trailer combinations.

A computer program known as TRUCKY was developed to calculate the operating costs, fuel consumption, total payload per 100 vehicles, total number of loaded vehicles, total number of vehicles to carry the same load, 80-kN single-axle-load equivalencies for front axles per 100 vehicles, and 80-kN single-axle-load equivalencies for nonfront axles per 100 vehicles for rigid and flexible pavements. Single-axle-load equivalencies, total payload per 100 vehicles, total number of loaded vehicles, and total number of vehicles at future limits are based on truck weight data supplied by federal and state highway agencies.

The highways were classified into three categories:

Table 2. Truck fleet mix by percentage of commodity tonnage transported.

Commodity Number	Commodity	Tonnage by Truck Type (%) 3-S2	Twin 8-m Trailers	Twin 12-m Trailers	Triple 8-m Trailers
	Agricultural goods				
1	Nonrefrigerated	83		17	
2	Refrigerated	58		42	
3	Forest products	58		42	
4	Bulk extractive resources	100		0	
5	Fuels, oils, and chemicals	45		55	
6	Building materials	50		50	
7	Textiles and textile products		30	55	15
8	Pulp, paper, and printed material		20	70	10
9	Furniture and household goods		5	90	5
10	Transportation equipment		0	0	0
	Manufactured goods				
11	Light		35	56	20
12	Medium	27		73	
13	Heavy	20		80	
14	General freight		50	25	25

Note: 1 m = 3.3 ft.

Table 3. Average payload by commodity and region.

Commodity Number	Average Payload (t) by Region National	West	Midwest	Southwest	East
1	15.06	16.62	15.17	14.40	13.97
2	15.64	16.74	15.89	14.65	14.62
3	14.32	16.47	12.83	14.27	13.50
4	18.99	19.49	18.87	18.71	19.68
5	15.44	16.12	16.29	15.95	14.66
6	15.36	16.69	15.50	15.79	15.32
7	10.22	9.35	10.62	10.86	9.62
8	11.40	13.53	11.07	12.32	9.52
9	6.54	7.57	6.15	6.75	7.54
10	11.00	9.57	11.75	10.50	9.72
11	13.32	13.41	13.38	14.11	12.82
12	10.08	11.31	9.78	10.59	10.52
13	15.32	14.91	15.74	14.53	15.37
14	10.77	12.08	11.04	11.22	10.40

Note: 1 t = 1.1 tons.

Interstate highways, farm-to-market roads, and other main roads (including U.S. highways and state highways). A uniform terminal serviceability index, slab thickness for rigid pavement, and structural number for flexible pavement were assumed for each class of highways.

Six types of vehicles were selected for evaluation because of their importance in the traffic stream. Figure 1 shows the four types of vehicles evaluated for scenarios A and B. These four vehicles are included in the six vehicles evaluated in scenarios C and D, shown in Figure 2.

The model for fuel consumption that was selected from a review of the literature (5-9) relates fuel consumption to GVW. The assumption for 80-kN single-axle-load equivalencies is based on formulas of the American Association of State Highway and Transportation Officials (10).

To calculate benefits and costs under various scenarios, the distribution of vehicle weights must be properly reflected. However, since only the weight data under pre-1975 limits were available when the project started, there was a need to shift the present weight distribution to obtain a most likely weight distribution under the future limits. As more data were gathered and analyzed, the NCHRP Report 141 shifting procedure was found to be inaccurate. Modifications were made, and an improved version—referred to as the SDHPT shifting procedure—was instituted. This procedure is discussed in detail elsewhere (2).

A truck-fleet-mix forecast was needed for each of the four scenarios. For scenarios A and B, a forecast based on historical trends was used for all four vehicles currently allowed on Texas highways. In making the truck-fleet-mix forecast, which was an extrapolation of historical trends, guidance was obtained from experience in other states, possible commodity shifts, and highway class. Based on this forecast and the average payload obtained from the TRUCKY program, ton-kilometer estimates were assigned to each vehicle type for the next 20 years.

For scenarios C and D, a procedure was developed to make possible a feasible forecast because there were no statewide historical trends for the 3-S2-4 and 2-S1-2-2 truck types. The procedure devised consisted of several assumptions that required sensitivity testing.

First, a commodity-specific forecast was made. All commodities were classified into 14 categories, as in the Hansen Associates study (3). Based on the characteristics of the commodity, a percentage of the total tonnage carried was assigned to each of the four types of vehicles (see Table 2). Commodities 1-6, 12, and 13 are high-density commodities and thus are assigned to truck types 3-S2 and 3-S2-4, both of which are suitable for high-density commodities. Commodities 7-11 and 14 are of lighter density and so are assigned to truck types 2-S1-2, 3-S2-4, and 2-S1-2-2, all of which are suitable for bulky commodities.

No switch in ton-kilometer estimates for types 2D and 3A to larger vehicles was assumed for scenarios C and D. It is possible that, because of the unique characteristics of the commodities carried by these two types of vehicles, there could be a significant switch, but lack of pertinent data restricted the analysis to the use of the "no-switching" assumption.

Since the ton-kilometer estimates assigned to types 2D and 3A are assumed to be the same, only the estimates assigned to types 3-S2 and 2-S1-2 were redistributed in scenarios C and D to the four larger vehicles.

The number of truck ton kilometers assigned to each highway class system in the state is based on a projection through the year 1997 (2). Of intercity truck ton kilometers, 47 percent is assigned to Interstate highways, 45 percent to other state highways, and 8 percent to farm-to-market roads. For each highway system, each commodity is assumed to control a certain share of the fixed amount of ton kilometers. This percentage is based on commodity data contained in the recent Hansen Associates study (3). Table 3 gives average truck tonnage by commodity and region, and Table 4 gives the percentage distribution of truck kilometers by commodity and region. The product of truck tonnage and truck kilometers yields estimated truck ton kilometers for each commodity in four regions in the southwest region of the United States. Because of the lack of commodity information for Texas and the nature of economic activities in the various regions of the state, the average of four multistate regions was used to represent a possible Texas situation. From these assumptions, a forecast of truck ton kilometers by highway class was estimated.

Since the trucking industry would not be able to convert instantaneously to the larger truck combinations, a 14-year transition period for full implementation was used for scenarios B, C, and D. Ninety percent of the affected freight-haul demand would be free to use the larger or heavier trucks in the first 8 years. The remaining 10 percent by assumption could use the system by the end of the 14 years (2).

The results obtained from the TRUCKY program and forecasts of ton-kilometer distribution were used to compute the 80-kN single-axle load for rigid and flexible pavements, truck operating cost, and fuel consumption for the 20-year analysis period.

Table 4. Distribution of truck kilometers by commodity and region.

Commodity Number	Percentage of Interstate Truck Kilometers by Region: West	Midwest	Southeast	East
1	19.95	17.83	15.82	12.93
2	9.87	5.95	7.01	3.94
3	4.17	1.26	3.35	0.74
4	0.17	0.72	0.95	0.95
5	12.04	7.09	10.06	10.67
6	2.10	2.22	2.10	4.91
7	1.83	1.28	6.28	1.71
8	4.07	4.98	5.68	6.23
9	0.63	0.74	0.85	0.57
10	1.26	1.94	1.35	1.30
11	4.53	5.08	6.44	8.32
12	5.25	6.34	4.63	5.37
13	7.38	17.41	8.65	15.15
14	26.76	27.15	26.83	27.19

Table 5. Comparative 20-year costs for four scenarios.

Scenario	Cost Item	Cost (millions constant 1977 dollars): Interstate Highways	Farm-to-Market Roads	Other State Highways	Total State System
A	Pavement maintenance and seal coats	240	1100	960	2 300
	Pavement rehabilitation	1334	1512	3084	5 930
	Bridge replacements	4	76	50	130
Total		1578	2688	4094	8 360
B	Pavement maintenance and seal coats	240	1100	960	2 300
	Pavement rehabilitation	1888	1953	4618	8 459
	Bridge replacements	172	376	554	1 102
Total		2300	3429	6132	11 861
C	Pavement maintenance and seal coats	240	1100	960	2 300
	Pavement rehabilitation	1426	1524	3178	6 128
	Bridge replacements	4	79	52	135
Total		1670	2703	4190	8 563
D	Pavement maintenance and seal coats	240	1100	960	2 300
	Pavement rehabilitation	1595	1590	3485	6 670
	Bridge replacements	46	152	264	462
Total		1881	2842	4709	9 432

Table 6. Comparison of inputs to REHAB.

Type of Highway	Type of Pavement	80-kN Equivalent Axle Loads per 20 Years by Scenario: A	B	C	D	Ratio of Pavement Life with Respect to Scenario A: A/B	A/C	A/D
Interstates	Flexible	7 813 000	12 980 000	8 558 000	9 919 000	0.602	0.913	0.788
	Rigid	11 720 000	20 250 000	12 033 000	14 413 000	0.579	0.974	0.813
Farm-to-market roads	Flexible	92 800	194 800	94 300	101 800	0.476	0.984	0.912
	Rigid	141 100	278 800	134 000	149 000	0.506	1.053	0.967
Other state highways	Flexible	871 700	1 602 000	877 000	989 000	0.544	0.993	0.881
	Rigid	1 308 000	2 435 000	1 227 000	1 422 000	0.537	1.066	0.920

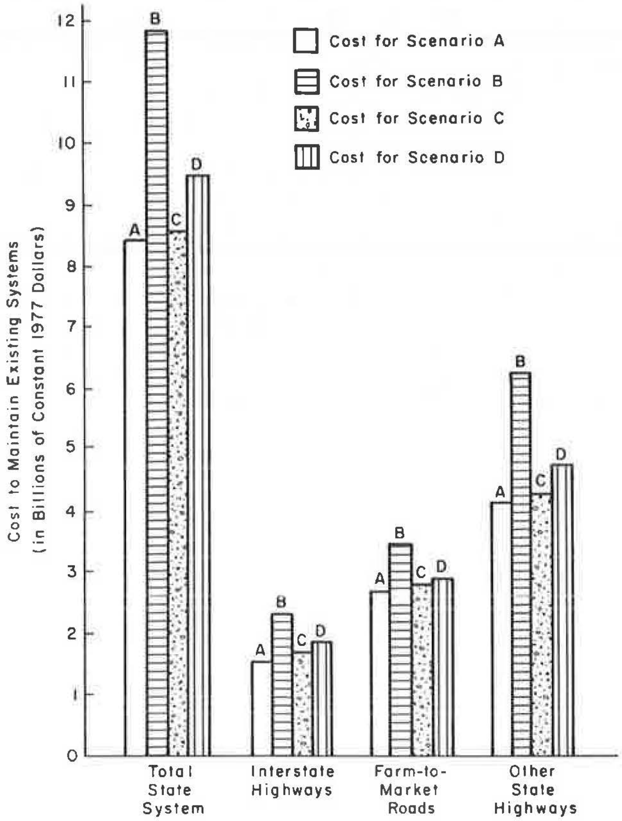
Note: 1 kN = 224.8 lbf.

Table 7. Comparison by ratio of highway costs, savings in truck operating costs, and fuel savings among scenarios for 20-year period.

Category	Total Highway Systems: B/A	C/A	D/A	Interstate Highways: B/A	C/A	D/A	Farm-to-Market Roads: B/A	C/A	D/A	Other State Highways: B/A	C/A	D/A	County Roads and City Streets
Additional highway cost (billions of constant 1977 dollars)	3.50	0.20	1.07	0.72	0.09	0.30	0.74	0.02	0.15	2.04	0.10	0.62	Unknown
Savings in truck operating costs (billions of constant 1977 dollars)	9.12	11.09	12.65	4.57	6.63	7.40	0.71	0.50	0.59	3.84	3.96	4.65	Unknown
Fuel savings[a] (millions of cubic meters)	9.16	11.29	13.24	4.62	6.72	7.75	0.69	0.53	0.61	3.93	4.05	4.89	Unknown

Note: 1 m^3 = 6.28 bbl.
[a] Fuel cost savings are included in truck operating costs.

Figure 3. Twenty-year cost (1977-1997) to maintain existing highway system, excluding city streets and county roads.



FINDINGS

The 20-year costs for all four scenarios are summarized in Table 5, where they are defined by highway class and expense item. For comparison, the impact of scenario C on highway pavements and bridge replacements is only marginally higher than the impact of costs anticipated under current laws governing truck sizes and weights in Texas (scenario A). As expected, scenario B would be the most expensive scenario in the long run. It is important to note that the cost of bridge replacements includes only the estimated cost of upgrading bridges to carry the loads included in the scenarios. The costs of structure maintenance, bridge replacement, and rehabilitation attributable to functional deficiencies and wear-out are not included because of the inability to isolate structural maintenance requirements associated with heavy loads and the lack of current technology for analyzing the effects of repetitive heavy loadings on the life of structures. The totals, therefore, do not reflect the entire cost of maintaining the existing system.

As a basic element in the computation of some of the pavement-related costs in the preceding, the findings of the AASHO Road Test were integrated into a computer program called REHAB to compute the 80-kN equivalent axle loads over a 20-year period by highway class and by type of pavement (flexible or rigid) for each scenario (see Table 6). It is interesting to note that, in the comparison of scenarios A and C, the results indicate that scenario C compares favorably. Scenario B is the most detrimental case in terms of equivalent axle loadings. When the results of the output on pavement and bridge impacts are compared, scenario C, as projected over the next 20 years, is not much different from the existing situation.

As the next step in the analysis, the scenarios were compared on the basis of operating costs, including fuel consumption. Table 7 gives a summary of the differential operating costs, in 1977 dollars, over 20 years by highway class and scenario. For the most part there is no significant difference in the ratio of operating costs for scenarios B, C, or D with respect to scenario A. Obviously, all were found to provide savings over the existing situation (scenario A). In terms of fuel consumption (Table 7), similar observations and findings are suggested. For another perspective, Figure 3 shows the estimated costs of perpetuating the existing system, in billions of constant 1977 dollars, over the 1977-1997 period. These costs exclude consideration of county roads and city streets.

CONCLUSIONS AND RECOMMENDATIONS

The analysis described in this paper suggests that, based on the cost increases for pavements and bridges alone, scenario C should be allowed. It is important to note that the pavement and bridge effects do not represent the complete set of impacts associated with each scenario. To complete the direct costs of each alternative scenario, an investigation has been initiated to develop costs associated with geometric design requirements and public safety.

Although quantitative estimates of these effects are not yet complete, the results of other studies suggest the importance of several safety-related aspects in an overall evaluation of large vehicles in the traffic stream. These include, but are not limited to, such elements as passing maneuvers, splash and spray, braking and stopping characteristics, vehicle maneuverability, and increased truck widths. In addition, quantifiable estimates of the effect of larger trucks on accidents, accident rates, and accident severity are needed.

In dollar terms, the most important effects of longer and wider trucks will likely result from the need to improve the geometric design features of the affected highway network. Substantial costs will be incurred to widen lanes, improve shoulders, alter passing lanes, adjust turning radii, and so on. Concepts such as marshalling yards, truck routes, load zoning, deregulation, law enforcement, small automobiles, and effects on city streets and county roads must be investigated. Estimates of these and other improvement costs are clearly needed before an informed judgment can be made about the efficiency of large vehicles.

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Improving the Effectiveness of a Citizens' Regional Transportation Committee

Peter M. Lima

The roles performed by the citizens' regional transportation committee that operates in the Omaha-Council Bluffs metropolitan area, a major midwestern region located in the states of Nebraska and Iowa, are discussed. This committee participates in four primary roles: (a) advisory, (b) advocacy, (c) review and comment, and (d) participatory planning. Specific examples of each role are presented, and each role is then analyzed for its effectiveness in resolving transportation issues. In general, the review-and-comment and advocacy roles have been the most effective among the four roles because they encourage participation and are oriented toward project issues. Recommendations are made on how to improve the effectiveness of these two roles. The recommendations are directed primarily toward the project-implementation stage rather than the earlier stages of the planning process. Recommendations are also made to further improve the effectiveness of a regional citizens' committee by breaking down the transportation system into corridors or subareas. This step would help to encourage citizen participation earlier in the process by focusing on local as well as regional issues.

The purpose of this paper is to present observations and perceptions of a citizens' regional transportation committee and to suggest improvements to the advisory process followed by this type of committee. Since I am chairman of the committee in question, the viewpoint expressed here is that of the private citizen rather than the professional planner. The committee discussed here is one working committee among several in a formal citizens' advisory board of the Omaha-Council Bluffs Metropolitan Area Planning Agency (MAPA). The advisory board, which is the central focus of the planning agency's ongoing citizen-participation program, provides guidance to the agency with regard to comprehensive planning and systems-level transportation planning. One comprehensive analysis of citizen-participation techniques has documented various types of advisory committees and task forces (1). But the operation of an ongoing regional committee cannot be easily categorized; it is complex and involves functions that are not restricted to giving advice on the long-range planning process. Rather, the committee members may participate in A-95 review or may become advocate planners for a certain project. These different roles then contribute in varying degrees to the effectiveness of the participation program in resolving transportation issues.

It is the intent of this paper to discuss how these roles can be used to the best advantage to improve the overall effectiveness of such an ongoing committee. In this regard, the following sections of this paper present descriptions of the Omaha-Council Bluffs metropolitan area, the regional transportation planning process, and the citizens' transportation committee. The paper then presents observations and perceptions of this transportation committee and offers suggestions for improving the effectiveness of regional committees.

DESCRIPTION OF METROPOLITAN REGION

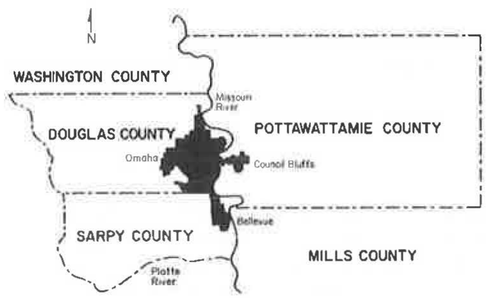
The Omaha-Council Bluffs standard metropolitan statistical area (SMSA) (see Figures 1 and 2) is composed of Douglas and Sarpy Counties, Nebraska, and Pottawattamie County, Iowa, and includes more than 20 incorporated cities, towns, and villages. Among these municipalities, the three most important are the cities of Omaha and Bellevue in Nebraska and Council Bluffs in Iowa. The Missouri River, a primary inland waterway, divides the region into the Nebraska and Iowa portions, and the Platte River borders the southwestern portion of the region. Within the SMSA, the physical terrain is a gently rolling landscape with only a few natural barriers to urban development, the most prominent of which are the floodplains of the Missouri and Platte Rivers and the wind-deposited loess hills on the east bank of the Missouri River.

As a result of limited physical restrictions on growth and intense agricultural activity, the Omaha-Council Bluffs SMSA grew in population from 100 000 inhabitants in 1870 to more than 600 000 by 1976. Historically, urban growth concentrated in the city of Omaha, which currently accounts for more than 60 percent of the total SMSA population. More recently, the pattern of growth has shifted to the southwestern portion of the region and is primarily concentrated in the city of Bellevue and in Sarpy County. Although the Omaha-Council Bluffs area has undergone significant urban development, the amount of developed land accounts for only 10 percent of the total land area. Hence, the SMSA remains oriented toward agriculture, which continues to be the economic mainstay of the region. Since 1950, however, agriculturally oriented employment has declined, and employment in the trades and services has grown.

Although the central business districts (CBDs) of Omaha and Council Bluffs constitute the traditional urban core, the metropolitan region has undergone intensive decentralization over the past decade. In general, urban development has sprawled outward,

Figure 1. Location map of Omaha-Council Bluffs SMSA.

Figure 2. Omaha-Council Bluffs SMSA.



and this has resulted in a low-density pattern serviced by lineal commercial development. This fairly rapid suburbanization of the region resulted in the following transportation inefficiencies: (a) uneven distribution of highway capacity throughout the region, (b) low rates of automobile occupancy, (c) severe limits on alternate modes to the automobile, and (d) noise pollution, air pollution, and energy waste as by-products of sprawling development (2).

REGIONAL TRANSPORTATION PLANNING AND PROGRAMMING

The regional planning agency, MAPA, was formed in 1967 under an interlocal cooperation agreement for the purpose of coordinating local planning and development activities (the planning region includes the SMSA plus Washington County, Nebraska, and Mills County, Iowa). The agency is governed by a 44-member council of officials that meets quarterly to set policies, goals, and objectives for the agency. A nine-member board of directors then implements this policy and directs the planning staff. MAPA is the designated planning agency in a variety of program areas, including (a) A-95 review, (b) land use and housing planning, (c) air quality planning, (d) water-quality-management planning, and (e) long- and short-range transportation planning.

Within the Omaha-Council Bluffs metropolitan area, the Continuing Omaha-Council Bluffs Metropolitan Area Transportation Study (COATS) is the designated metropolitan planning organization (MPO) to carry out the urban transportation planning process. This multi-agency organization is structured along the traditional comprehensive, continuing, and cooperative (3C) organizational pattern, which consists of a policy committee, a technical committee, a technical staff, and a citizens' advisory committee (see Figure 3). Since COATS is an integral part of MAPA, the MAPA board of directors acts as the policy committee for the transportation study (the COATS transportation study includes the urbanized portion of the SMSA). Furthermore, MAPA provides the lead technical staff for the regional transportation planning process as well as the overall comprehensive planning process, and additional technical assistance is provided by the Nebraska Department of Roads and the Iowa Department of Transportation. The members of the technical advisory committee function as advisors to the board of directors and the technical staff, and they also act as coordinators between the staff and the local implementing agencies. In addition to the advice given by the technical committee, the citizens' transportation committee performs an advisory function for the MAPA staff.

The COATS process involves a variety of tasks:

1. Coordination of transportation activities throughout the metropolitan region,
2. Development of a long-range regional transportation plan,
3. Development of a short-range transportation plan in the form of a transportation system management (TSM) element, and
4. Preparation of a transportation improvement program (TIP) that consists of an annual element and a subsequent five-year element.

The COATS 1995 Interim Transportation Plan, adopted in 1974 and subsequently amended, is currently the official long-range plan that guides local and state decision makers in the allocation of available resources. Based on the 1995 plan, both highway and transit projects are selected, prioritized, and placed on the TIP. In addition to projects selected from the long-range plan, the TIP includes projects listed in the TSM element of the transportation plan. Once a project is placed on the TIP, the agency or agencies responsible for that project generally initiate work leading toward the implementation of the project.

THE TRANSPORTATION COMMITTEE

As previously mentioned, the transportation committee is a working committee of the larger and more comprehensive citizens' advisory board, which was formed to involve private citizens from all socioeconomic segments in the planning for the five-county region. Membership on the advisory board may include representatives of the business community, labor organizations, minority organizations, chambers of commerce, and special-purpose organizations as well as private citizens. Each member is nominated by the advisory board's executive committee and subsequently appointed by the board of directors. The advisory board can make recommendations to the staff, the technical committees, and the board of directors. Five working committees form the nucleus of the board's activity: committees on (a) community involvement, (b) human resources, (c) regional growth and development, (d) natural resources, and (e) transportation. Although the advisory committee formulates broad policy, each committee follows its own work plan. Moreover, each committee can issue its own statements and recommendations without the vote of the whole advisory board as long as the statements are issued in the name of the committee. Thus, all substantive participation is accomplished within one of the five working committees.

Currently, the transportation committee is composed of a chairman, a vice-chairman, and approximately 15 members whose interests include transportation for the elderly and the handicapped, environmental conservation, pedestrian and bicycle

Figure 3. Structure of Omaha-Council Bluffs transportation planning organization.

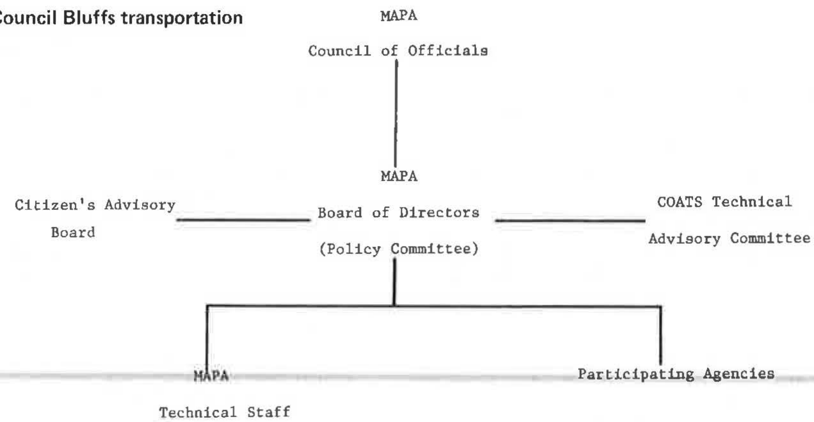
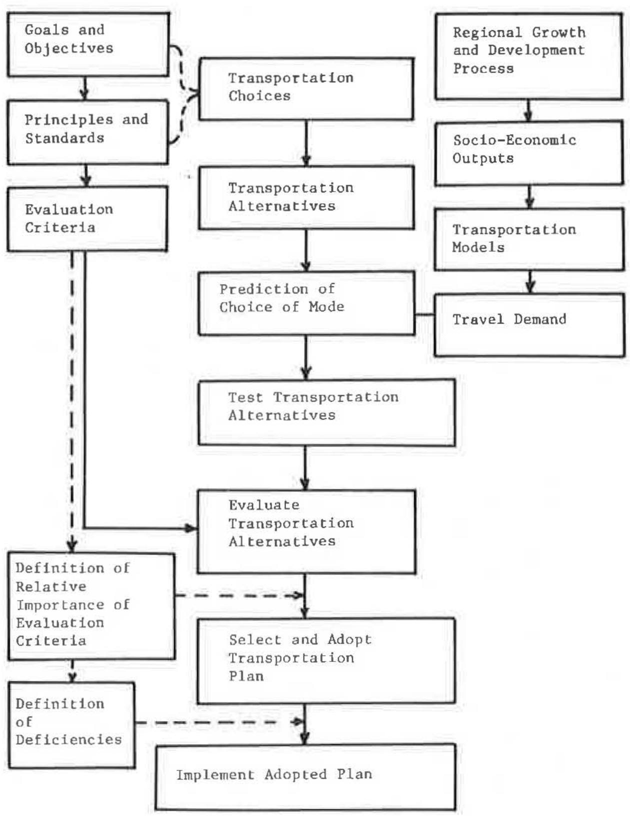


Figure 4. COATS year-2000 planning process.



transportation, and efficient highway and transit transportation in general. The chairman of the committee is also a member of the advisory board's executive committee and a nonvoting member of the transportation technical advisory committee. His or her membership on the technical advisory committee, even with only nonvoting status, definitely strengthens the link between the technologists and private citizens.

Each monthly committee meeting is based on a predetermined agenda jointly prepared by the committee chairman and the director of the planning agency's transportation department. The agenda usually focuses on an important transportation issue or planning activity and generally includes routine items such as A-95 review cases. This brings up an interesting point—the fact that the committee does not have a formal charge. However, the charge can be broadly interpreted, as follows: to provide continuous guidance, which is sensitive to the needs and wants of the regional populace, to the planning staff in the preparation of long- and short-range regional transportation plans. With respect to the specific activities that have been carried out by the committee over the past two years, each activity can be categorized by a particular committee role: (a) advisory, (b) advocacy, (c) review and comment, and (d) participatory planning. The following discussion elaborates on these roles and presents example roles played by the transportation committee.

Advisory Role

As noted above, the advisory role is the broad function of the transportation committee. But, more specifically, the advisory role of the committee is to provide advice to the transportation staff on the perceptions, needs, and desires of the people in the region with regard to regional transportation issues. For example, the identification of transportation goals, objectives, and evaluation criteria for the Omaha-Council Bluffs area would be part of the advisory role; in fact, the committee made significant contributions to the development of the evaluation criteria for the year-2000 plan [Figure 4 (3, p. 2) shows the year-2000 planning process]. Generally, advisory functions are primarily concerned with policy issues rather than project issues, which would be handled in the advocacy or the review-and-comment role.

Advocacy Role

The distinction between the advisory and advocacy roles is that in the advocacy role a citizen takes a definite position on a given project or policy statement. For example, the committee has supported the need to expand pedestrian opportunities in general, but it has also advocated the construction of a specific recreational trail in Douglas County and presented testimony at a public hearing on behalf of the trail. Although the committee's support of the trail contributed to the decision of the county board of commissioners to fund preliminary studies, the project was ultimately defeated because of complaints from the owners of adjacent property. On the policy side, the committee presented testimony with regard to maintaining strong photochemical standards for the states of Nebraska and Iowa. The committee was not successful in this case but did have an opportunity to present its viewpoint on air quality planning.

Review-and-Comment Role

In the review-and-comment role, each citizen reviews specific proposals and plans and then reacts to them in the form of verbal or written comments. The committee regularly reviews the regional A-95 cases and makes comments on these cases to the staff, which in turn forwards the comments to the technical advisory committee and to the board of directors. In cases in which the committee formulates strong comments against a particular case, the chairman or another committee member will present the committee's comments to the technical advisory committee. It is interesting to note that the review of a proposed plan often evolves into an advocacy position by the committee. As a case in point, the review of the proposed recreational trail eventually developed into active support for the trail.

Of course, the committee sometimes takes an adversary position after reviewing a particular project. For example, the committee reviewed a proposal by the Nebraska Department of Roads to construct a new roadway through a fish hatchery and nature area in order to improve vehicle safety. In light of what the committee interpreted as weak evidence in support of the project, members took a strong, almost an advocacy, position against the project and recommended alternatives. As a result of the comments of the committee and others, the Nebraska Department of Roads is reconsidering its original proposal and rewriting the environmental impact statement.

Participatory Planning

As referred to here, participatory planning means the active involvement of the committee members in developing original plans or even policy statements. In an attempt to generate enthusiasm among citizens, the transportation committee initiated its own study of pedestrian facilities in the Omaha-Council Bluffs region. The primary purpose was to develop guidelines for pedestrian and bicycle transportation to be used in long-range planning. The results of this planning initiative have been disappointing because the committee members have been subject to time constraints and have not been able to contribute to the study as originally intended. However, the work that has been accomplished has at least generated interest in pedestrian and bicycle transportation among citizens and professionals in the region.

In general, the members on the transportation committee conduct initiative planning through their advocacy and participatory-planning roles and carry out reactive planning through their advisory and review-and-comment roles. The next aspect to be examined is the effectiveness of each one of these roles in responding to and resolving transportation issues.

OBSERVATIONS AND PERCEPTIONS

The goal of any citizen-participation program is the timely and orderly resolution of transportation issues among all parties concerned. A regional advisory committee such as the one outlined above achieves this goal to varying degrees depending on the specific role the committee plays.

Before each role is examined in more detail, two general points must be made. The first is that, because of the committee's small size, representation of the metropolitan population as a whole is limited. This limitation does not occur by design but reflects the difficulty in attracting participants to systems-level planning. The second point is that restricted representation is further complicated by the type of person who participates on the committee. Such a person is often the "professional" citizen who is very interested in and informed about regional issues and participates on a regular basis. This is not to say that such a member's contribution is not valuable; rather, it is to say that it is probably not representative of the larger population. At first glance, then, the overall effectiveness of the committee appears to be questionable, but further analysis indicates that the committee does in fact play a definite role in both clarifying and resolving issues.

In its pure form, the ongoing advisory role is a difficult one to carry out because it involves a slow, meticulous, and often painful process. Furthermore, the exact contribution of this role to the resolution of issues is not easily assessed. For example, although a committee may work diligently on formulating regional goals and objectives, the overall contribution of this effort to the planning process cannot be evaluated for several years. In fact, the effort probably will not be evaluated and, as a result, the individual participants may lose interest in this role. Although the overall effectiveness of this role in resolving issues is difficult to assess, the ongoing advisory role has two important impacts on the planning process:

1. Through the ongoing advisory role, a regional committee maintains the continuity of citizen participation throughout the process, thereby ensuring that the staff and politicians remain responsive to citizen input at all times.
2. The members of the committee can broaden the staff's knowledge of the region and can guide it with respect to citizen perceptions and needs.

The advocacy role is issue based. It is a positive role that forces individuals to analyze facts, take a position on an issue, and then formulate alternate recommendations. Since people gravitate easily toward the advocacy function, it encourages participation. In fact, it appears to be the most interesting of the four roles for most participants. But it is a dangerous role for a small group to play—i.e., for a limited number of individuals to perform as advocates for projects that may affect many people at a more localized scale. What is needed is the involvement of more people at the local level, in the early stages of the planning process. It is difficult to involve more individuals at an early stage because the implementation of the project is usually remote. But, since the advocacy role definitely brings out the issues and helps to resolve them among citizens, professionals, and political decision makers, it should be emphasized and broadened by a regional committee.

In the review-and-comment role, a citizen is presented a plan by the staff and is then asked to express his or her opinion of the plan. In general, committee members are comfortable in this reactive role and actively participate on a regular basis. Of course, a committee can review many different types of plans, but this role is highly effective in resolving issues with regard to relatively small-scale projects.

Along this line, the A-95 review process is an effective mechanism for citizen review of projects that are at the implementation stage. Citizen review of A-95 cases helps to broaden the objectivity of the technical committee, which also reviews these cases. Technical committees sometimes gloss over a particular case, either for expediency or because one committee member may have a vested interest in the project. In addition, the committee may fail to perceive the importance of some project issue. For example, the technical committee may neglect pedestrian facilities in a subdivision case, whereas this might be highly important to the citizens' committee. Here, the citizens' committee can be very effective in identifying project issues and noting weaknesses in a given plan.

As used here, the term participatory planning refers to initiative planning by citizens that includes data collection, analysis, and plan preparation. This is a highly energy-consuming role for a committee to take on and, unless the committee members are extremely interested in a particular project, the effort will be fruitless. The best way to handle participatory planning is to narrow the scope of the project. Along this line, the committee can prepare observations, perceptions, and/or policy statements on a particular project. In some cases, the committee can present its own additions to the regional transportation plan prepared by the staff. This would be in the form of a supplemental report issued by the committee.

Although I was not involved, the transportation committee was highly successful in integrating their own project proposals into the Omaha-Council Bluffs 1995 transportation plan. This was very effective participatory planning, but again the role was enacted largely at the end rather than at the earlier stages of the process. Involvement at the end of the process may be unavoidable because the participants need to have a substantial amount of technical groundwork laid before they can actually initiate planning on their own.

The citizens' transportation committee in the Omaha-Council Bluffs metropolitan area has participated in a variety of roles, ranging from the pure advisory role to the participatory planning role. In general, the committee roles that are based on the transportation issues and deal with specific projects at the implementation stage have been helpful in resolving transportation problems. In this regard, the review-and-comment role, particularly as applied to A-95 cases, is effective. The advocacy role has also been successful in the clarification and resolution of issues. Although the participatory-planning role is oriented toward a given project, it has only been moderately effective because it involves a large commitment by the committee. Ironically, since this committee is an advisory committee, the pure advisory role appears to be the least effective of the four roles. This weakness results from the fact that the advisory role is often concerned with abstract ideas rather than concrete facts. Moreover, the exact impact of this role on the planning process is difficult to assess. But the potential information to be gained from this role, as from all the roles, is important.

IMPROVING EFFECTIVENESS OF A CITIZENS' REGIONAL COMMITTEE

This paper has repeatedly mentioned that the effectiveness of a citizens' regional committee should be improved, but it is difficult to place a quantitative measure of effectiveness on any type of participation program. With respect to the effectiveness of a participation program, one report (4, p. 17) notes the following:

> The important concepts are whether or not all affected persons were allowed an equal opportunity to participate, understood the planning process, and understood the issues of choice, and whether or not the contributions and preferences of these interests were given due consideration by the agency in making its decision.

Based on the above concepts and the observations set forth in this paper, the effectiveness of a regional transportation committee can be improved by (a) broadening committee representation, (b) basing participation on the issues and specific projects, and (c) pressuring the decision makers to make authoritative decisions on the resolution of the issues. The review-and-comment role and the advocacy role have the highest potential for meeting these qualifications since both encourage participation and are oriented toward project issues.

Although regional transportation planning is the topic here, the most effective roles for a citizens' committee to play are oriented toward the project rather than the systems level. But how does this project planning help systems planning, which is done at a much larger scale? According to Manheim and others (4, p. 90), one answer to this question is

> An examination of many transportation controversies leads to the conclusion that many of the problems are directly related to the inability of the present system planning process to explicitly deal with uncertainty and to effectively relate near-term programming decisions to longer-range system plans. System planning must focus not only on desirable master plans but also on implementation strategies.

Thus, strong citizen participation at the implementation stage can definitely strengthen the system planning process. If this is the case, how can the review-and-comment and advisory roles be used to best advantage?

The following recommendations will improve the effectiveness of the review-and-comment and advocacy roles at the implementation level:

1. A citizens' regional transportation committee must review A-95 cases on a monthly basis and forward its comments to the technical advisory committee. These comments should be submitted in written form and directed toward the project issues. Ideally, the committee's comments should deal with solutions to the problems of a particular case. Furthermore, the committee should follow up to ensure that its comments are given proper consideration and that they are acted on in one form or another. It will then have the necessary feedback to its input and will be able to initiate further action if it desires. For efficiency, each committee member must be given the appropriate material on each A-95 case well before the monthly meeting. In addition, it would probably be desirable to emphasize one or two cases at the meeting in order to conserve time.
2. The advocacy role can be strengthened in a similar way. If there is a given project in which the committee has a special interest, a consensus opinion on that project should be reached. The committee can then put its comments in a letter to the appropriate agency or agencies and ask for a reply to the letter. To make a strong case for its position, the committee must research the project issues and formulate strong arguments. If the reply is positive, no further action may be required. If the reply is negative, the committee can drop the matter, submit further evidence in support of its viewpoint, or go to a higher authority such as a congressman or senator.

It is my opinion that, if these two recommendations are carried out, the level of participation on the committee will increase. To achieve this, however, the roles must be carried out routinely and efficiently, and the community must be informed that the committee is performing these roles. Moreover, the successes of the committee must be documented and disseminated to the public. Ensuring open participation on the committee is important; otherwise, the committee will be an elite group with a strong voice. Care must also be taken to cover regional issues and not focus solely on local issues.

The recommendations given above can improve the effectiveness of the committee in the implementation stage. However, effectiveness must also be improved in the earlier planning stages. If the long-range system planning process is brought down to the local level, more individuals will participate in the process because local issues will be brought to the surface. One way to accomplish this is to base participation on the corridor or subarea level rather than on the system level. This approach has been successful in special-purpose studies such as the Boston Transportation Planning Review (5) and could be successful for an ongoing advisory committee. Such an approach is definitely oriented toward transportation issues and specific projects. To make the best use of this approach, the committee can be divided into subcommittees that are based on one or more corridors. This will help to focus on corridor issues and thereby stimulate interest among local community organizations. Furthermore, this approach should strengthen the advisory and participatory-planning roles by relating them to corridor issues.

As previously mentioned, the scope of the participatory-planning role must be limited and well defined. Participatory planning is usually more effective in the later stages than in the earlier stages of the systems planning process. For example, it would be more effective in the alternative selection stage than in the goals and objectives stage. The corridor approach would also strengthen the advisory role by focusing on local issues as well as regional issues. For instance, the committee might develop goals and objectives for a given corridor that support the regional goals and objectives.

The success of the corridor approach is severely limited by time and budget constraints and by the difficulty in managing the process, but the approach could be attempted on a limited basis for one corridor or one project. This would still necessitate a large effort on the part of the planning staff and the transportation committee. Nevertheless, this model could help to improve the committee's effectiveness in resolving issues by focusing on the vital issues.

CONCLUSIONS

The effectiveness of a regional citizens' transportation committee can be improved by emphasizing the use of the review-and-comment role and the advocacy role at the project implementation stage. These roles encourage participation and contribute to the resolution of transportation issues. Since project planning is clearly linked to systems planning, improved citizen participation at the project level will enhance the quality of the systems planning process. The planning for the system as a whole can be further improved by breaking the system down into corridors or subareas. The citizens' committee would then be divided into subcommittees based on these geographic stratifications. This step would not only improve the review-and-comment and advocacy roles but would also strengthen the advisory and participatory-planning roles.

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Effective Citizen Participation: Public Search for "Democratic Efficiency"

Richard Yukubousky

The question of how to achieve the democratic goals of public participation without resorting to a process that is cumbersome, frustrating, and costly to communities and public agencies is examined. The concept of "democratic efficiency"—the ratio of citizen satisfaction with planning outcomes to public participation resources "spent" in the planning process—is proposed as an aid in the design of public participation programs that are both democratic and efficient. Simple dichotomies that describe the critical trade-offs between democracy and process efficiency are used, and strategies, interaction techniques, organizational devices, and support resources that have high potential for achieving effective participation are suggested. Substantial gains in democratic efficiency can be achieved through staff training, technical assistance for community groups, meeting preparation, and public participation in the design of the citizen-participation process itself. Several promising interaction techniques that are not now widely used are identified for further research and development. These are citizen juries, assemblies to integrate subarea and area-wide transportation planning, and other structured interaction techniques.

Over the past decade, citizens, planners, and public officials have gained considerable experience in dealing with the complex issues of citizen participation in planning and decision-making processes. From a historical perspective, it has been a relatively short time since the question of whether or not citizen participation was desirable was being debated. Now concern has shifted to the question, How can we most effectively engage citi-

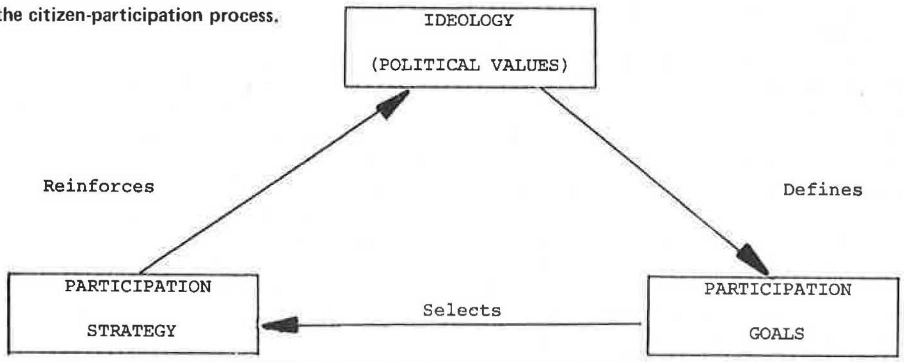

Figure 1. Ideology in the citizen-participation process.

Table 1. Ideologies, goals, and strategies in citizen participation.

Ideology	Goal	Strategy
Democratic	Identify values, goals, and needs (4, 5) Foster human development, e.g., reduce alienation, develop leadership skills, and enhance problem solving (6-8)	Consultation
Liberal	Increase political sophistication (9) Protect freedoms and liberties (9) Identify important social problems (9) Adopt marginal changes that ensure long-term societal stability (9)	Partnership
Socialist	Win power for the poor (3) Foster dignity and self-respect (10) Enhance solidarity and sense of community (11)	Advocacy and confrontation
Technocratic	Prevent obstruction of agency plans (6) Maintain agency stability Educate the public about decisions that have already been made (6) Change behavior (12)	Cooptation, manipulation, and therapy

zens, planners, and public officials in participatory planning processes?

This paper addresses one particularly thorny problem that cuts across most issues of effective participation: the multiple trade-offs between democratic citizen participation and efficiency of process. Citizens desire a planning process that is open, fair, representative, informative, and meaningful. People are reluctant to contribute their time, energies, and skills when they believe that planners and decision makers will not really give full consideration to their ideas and legitimate concerns. However, a process that conscientiously attempts to meet these objectives is usually more time-consuming and requires greater staff resources and patience and larger budgets than traditional technocratic processes, which permit little, if any, citizen participation. Planning administrators feel the crunch between democracy and process efficiency, too, especially when they must justify expanded budgets to facilitate participation and at the same time develop and manage work programs that produce timely products.

In research on neighborhood planning in Seattle, the most common citizen complaints were that Seattle's very democratic neighborhood planning process took too long, consensus projects were not implemented fast enough, important information was not readily available, meeting agendas were not well organized, and the planning process was attempting to meet conflicting objectives (1). These complaints are symptomatic of a planning process that is democratic but not efficient. Citizens become "burned out" by this process and express an unwillingness to participate in future community planning activities.

I believe that the biggest challenge facing citizen-participation specialists is to devise ways to facilitate the democratic goals of participation without resorting to a cumbersome, time-consuming process that wastes "people energy" and needlessly consumes community and agency resources. This paper discusses a number of suggested approaches that have high potential for accomplishing both the democratic and efficiency objectives of citizen participation.

IDEOLOGICAL ROOTS OF THE CONFLICT

Public planning is inherently a political process, since it deals with the distribution of important societal values (2). Thus, our first task in identifying effectiveness criteria for citizen participation must be an examination of the sociopolitical values on which that process will be built. Figure 1 shows why this task is so important.

Ideologies (or sociopolitical values) define goals for public participation. These goals guide the selection of participation strategies. In turn, the successful implementation of those strategies is supposed to reinforce the values on which the ideology is founded. Our task would be greatly simplified if all citizens, planners, and public officials shared the same sociopolitical values because we would then have near consensus on what the goals and proper strategies of participation should be. This is not the case. Other writers have convincingly demonstrated that several important ideologies may be brought to the planning arena by diverse participants (3). Table 1 gives an overview of important ideologies, related goals, and associated strategies of participation.

Political analysts generally agree that the American political system is most strongly influenced by the political philosophies of classic democracy and liberalism. Both ideologies assume the primacy of individuals as the best judges of their own interests. Most modern interpretations of democratic theory do not call for a devolution of political power. Therefore, the strategy of participation that is most generally associated with democratic theory is that of consultation. Opinions, attitudes, and inputs are sought but only to advise planners and policymakers. After full consideration of all viewpoints, elected public officials make decisions. Citizens neither control budgets, devise policy, nor hire and fire staff. When using the consultation strategy, citizens define the goals, but rarely the means, of planning (3). Goal-setting exercises, public hearings, surveys, analysis of client needs, and other indirect citizen-participation techniques are frequently used in a strategy of consultation.

Whereas democratic theory defines the public interest through majority vote, liberal theory is much more complicated in that the public interest is defined through the interplay of multiple minority-group interests (13).

Thus, the strategies of participation called for in liberal theory are also considerably more complicated. Through partnership strategies, citizens and power holders negotiate terms on how planning and decision-making responsibilities will be shared and establish ground rules that neither side can unilaterally dismiss in order to resolve impasses. Joint policy boards, planning committees, and bargaining and negotiating tactics characterize the partnership strategy.

Socialism provides a philosophical basis for people who are primarily concerned with equality and the advancement of the poor. Advocacy planning is a strategy of participation that has been linked to socialist theory (3), although others would argue that advocacy is merely an application of liberal theory (14). Since the poor lack the conventional sources of power needed to function effectively in the political arena, advocacy must frequently rely on a strategy of confrontation to achieve its goals.

A technocratic ideology often drives agency staff members who are overly concerned with order, progress, and efficiency (3). Citizen participation is frequently denied and, where it is permitted, the goals are usually to (a) prevent obstruction of agency plans, (b) maintain agency stability, and (c) educate the public about what has already been decided. The strategies of participation most frequently associated with technocratic planning are cooptation, manipulation, and therapy (15).

Even this brief examination of political ideologies suggests that there will not always be agreement on what the proper strategy of citizen participation should be. This is one reason why I believe that it is important to obtain citizen input in designing the public participation process. Otherwise there is grave risk that the structure and conduct of the participatory planning process itself will become a heated public issue that damages the credibility of the planning effort. Moreover, this brief review suggests several obstacles to our quest for democratic efficiency:

1. Democratic and efficiency goals derive from different ideologies. Democratic goals are embellished in democratic and liberal value systems, whereas efficiency goals are best articulated in technocratic theory, which is at best antidemocratic.
2. Ideological issues are rarely resolved through so-called "rational" debate and analysis, since different ideologies usually have quite diverse standards of rationality.

CONCEPT OF DEMOCRATIC EFFICIENCY

Simply defined, democratic efficiency is the ratio of public satisfaction with planning outcomes to the citizen-participation resources "spent" in the planning process. The ideal is instantaneous consensus (complete satisfaction) without having to expend any resources. This definition is comprehensive to the extent that all citizen-participation resources, including citizens' time, expertise, and out-of-pocket expenses, are recognized. However, I do not believe that it is either possible or desirable to quantify the variables in the "formula". Hypothetically, one can concoct examples that show that a process that achieves 40 percent consensus while using very few citizen-participation resources is more democratic and efficient than a process that achieves 90 percent consensus but expends far greater resources. The chief problem with such a comparison is that it ignores a significant political reality—i.e., a project that gets 40 percent support is unlikely to be implemented if the other 60 percent of the public opposes it. Nor does the formula enlighten us about how to allocate citizen-participation resources among major and minor planning studies; there is evidence that larger planning studies generally require a smaller proportion of their total planning budget for citizen-participation activities (16). Despite these caveats, the concept of democratic efficiency provides a useful, although primitive, tool to aid in the search for efficient techniques that accomplish democratic goals.

DESCRIPTIVE MODEL OF PARTICIPATION

Figure 2 is an adaptation of the descriptive model of citizen participation that was recently developed at the University of Washington (17). The model incorporates the results of more than 10 years of empirical research and evaluation in citizen participation. Since the model approximates the relationship among important variables, it provides a useful starting point in the quest for citizen-participation strategies that are both democratic and efficient.

Issues—their history, character, and implications—give people a basis for deciding whether or not to become involved. Issues also influence the selection of participation strategies. For example, a controversial urban freeway issue will generally require a more complex participation structure than that required to resolve disputes over a rural bypass route. Participants—their

Figure 2. Descriptive model of citizen participation.

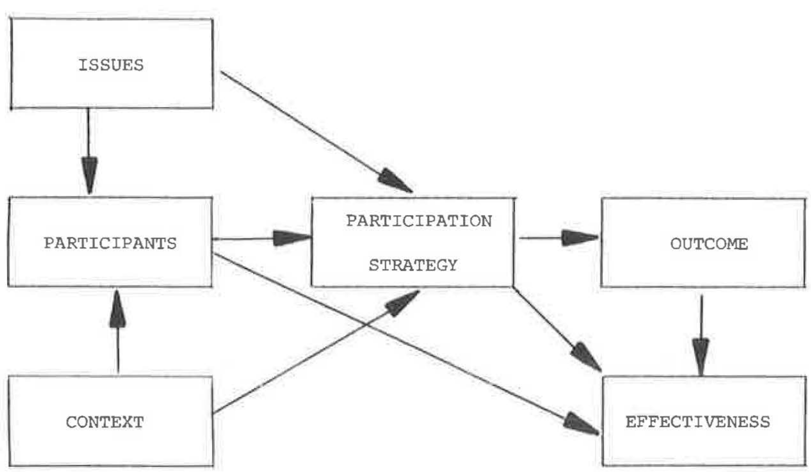

Table 2. Achieving democratic efficiency in citizen participation.

Item	Characteristic: Democratic	Characteristic: Technocratic	Democratic Efficiency
Number of participants	Many	Few	Substantive representation, assemblies, subarea planning
Number of goals	Many	Few	Priority-setting workshops
Decision rule	Majority rule	Elite decision making	Consensus seeking
Representation	Elected representatives, self-selection	Appointed representatives	Citizen juries
Citizen roles	Citizens initiate alternatives	Citizens react to proposals	Collaborative planning, design-ins, workshops
	Uninformed citizens	Experts	Citizen training, community technical assistance, gaming
	Community sets agenda	Staff sets agenda	Partnership
	Full citizen power	Little or no citizen power	Citizen representatives on policy board, arbitration, mediation, negotiation
Planner roles	Coordinator-catalyst, facilitator, counselor	Technical experts	Staff training for all roles
Support resources	Full disclosure of all information	Secrecy	Public information packets, design catalogs, project monitoring, community technical assistance
	Staff skilled in group dynamics	Staff lacking in group skills	Training of staff and community leaders
	Staff well-prepared	Staff ill-prepared	Good agendas, pretest communications, information packets
	Variety of citizen-participation resources	Few citizen-participation resources	Reimbursement of citizen expenses, citizen honoraria, advocates
Techniques	Unstructured interaction	Little or no interaction	Structured interaction, e.g., group process
	Intensive dialogue	Feed forward and feedback	Computer polling
Scheduling	Long planning study	Quick decision	No more than one year for planning study

past experiences, ideologies, motivations, positions in the community, and resources—also influence the selection of citizen-participation strategies. And finally, the institutional context for participation (source of funds, mandate, agency jurisdictions, governmental structures, etc.) often dictates the style of participation.

Note that the strategy of participation directly affects outcomes and effectiveness. Naturally, participants themselves influence the effectiveness of the participatory process. And, consistent with our definition of democratic efficiency, satisfaction with planning outcomes is related to effectiveness.

In reality, there are few opportunities to change issues or their context for resolution, although creative citizens and public officials can find exceptions. For example, in the West Seattle bridge issue, some citizens circulated a petition to secede from the city of Seattle and reincorporate as an independent city, thereby becoming eligible for state and federal funds to solve a critical transportation problem. In other cases, public officials have redefined issues to attract new participants. According to the model (Figure 2), redefinition of the issue or institutional context could result in changes in the participation strategy, which would in turn have an impact on outcomes and effectiveness. However, the key variable that influences the effectiveness of participation is the strategy or form of participation. Therefore, in attempting to identify effective strategies of participation, this paper concentrates on alternative interaction techniques, organizational structures, and resources for citizen participation.

TOWARD DEMOCRATIC EFFICIENCY

Specific suggestions for achieving democratic efficiency are discussed in the remainder of this paper. Table 2 gives a number of dichotomies that guided this analysis. The table identifies traits that are generally associated with democratic or liberal ideologies of participation and those generally associated with technocratic participation. I do not support technocratic, elite solutions to the citizen-participation dilemma. But, since efficiency is an important underlying value, we can look to technocratic ideology for examples of opposites or polar extremes to democratic traits. To find compromises that are both democratic and efficient, we need to identify solutions that are somewhere between the two extremes. Accordingly, the right-hand column in Table 2 presents what I judge to be promising resolutions.

Number of Participants

Our first consideration relates to the number of participants in the citizen-participation exercise. Representation has historically been the compromise between democracy and efficiency. According to Peterson (18), substantive representation of low-income and minority groups is highest where

1. There is an organized relationship between formal representatives and their constituency,
2. There is competition among those seeking to be formal representatives,
3. Formal representatives are educated and sophisticated about the political and decision-making processes, and
4. Formal representatives have substantial influence over the relevant program (i.e., there is incentive to take participation seriously).

Transportation planners are becoming more involved in planning at the subarea or neighborhood scale (19). Subarea planning is inherently more democratic than regional systems planning since (a) issues and potential impacts are more tangible, thus (b) attracting the participation of larger numbers of citizens. However, where there are important issues that need to be addressed at a regional scale, these studies can be organized around geographically based assemblies, a process in which each neighborhood or subarea appoints or elects representatives to a larger body that coordinates the interface among smaller-scale solutions.

As more people become involved, there is a corresponding increase in the number of articulated goals. Planning at any scale becomes frustrating and cumbersome when it attempts to achieve too many goals. Thus, it is strongly recommended that community workshops be formed early in the planning process to identify priorities and goals that should receive immediate attention. Early priority setting will focus the planning process on key issues, thereby streamlining the process and reducing the level of citizen frustration.

Representation

Democratic planning generally calls for elected representation or self-selection of citizen participants. By contrast, technocratic planning frequently relies on appointment of citizen representatives. A third possibility, which, to my knowledge, has not been tried, is the empanelment of citizen juries to hear pro and con arguments about alternative solutions and to select the best approach. Citizen juries could directly involve citizens who normally do not participate, provide better representation through random or quasi-random selection of citizens, and allow jury members to devote full-time attention by reimbursing them for their time. This alternative deserves more attention than it has received.

Roles

There is a basic dichotomy between initiative planning, in which citizens initiate proposals, and reactive planning, in which citizens merely react to agency proposals (20). Reactive planning is generally considered to be more efficient because technical experts are more skilled at framing and developing alternatives than citizens are. Certain techniques (e.g., "design-ins," workshops, and charettes) facilitate collaboration between citizens and planners in developing meaningful alternatives (5). However, truly successful collaborative planning depends more on technical assistance and citizen training than on the application of specific interaction techniques. Collaborative planning also requires the planner to perform as coordinator-catalyst, facilitator, and counselor in addition to technical expert. Most technical people have not had the training to effectively carry out these demanding roles, which require skills in community organization, group dynamics, interpersonal relations, and mediation. Staff training can pay handsome dividends in increased democratic efficiency.

Democratic planning devolves greater power and influence to citizens than does technocratic planning. A planning process that is both democratic and efficient will minimize the risks of reaching an impasse—e.g., through partnership arrangements that involve the community in setting the agenda for the planning study. The election or appointment of citizen representatives to policy boards is one technique by which to directly involve citizens in crucial deliberations over the design of citizen-participation programs, study agendas, programming, and scheduling. Major actors whose support is crucial for project implementation should concur about their respective roles, responsibilities, support services, and contributions to the process before the study is launched. During evaluation and decision-making activities, direct negotiations can sometimes resolve impasses between community groups and power holders. When all else fails, a third-party mediator or arbitrator may be employed to resolve serious conflicts.

Support Resources

Several researchers have concluded that the effectiveness of participation and satisfaction with outcome are related more to the diversity of citizen-participation resources than to the specific interaction techniques used (1, 17). There is a wide array of support resources that can substantially enhance the democratic efficiency of the citizen-participation process with modest increases in citizen-participation budgets:

1. Information—(a) public information programs, (b) data packages, (c) design catalogs, and (d) project monitoring (to provide better citizen information in the future about probable impacts);
2. Community skills and group dynamics—(a) staff training, (b) leadership training, and (c) community technical assistance;
3. Meeting preparation—(a) better meeting agendas, (b) pretest communications, and (c) information packets and brochures; and
4. Other supports—(a) citizen honoraria, (b) reimbursement for citizen expenses, and (c) advocates.

Techniques

By definition, democratic techniques call for direct involvement. On the other hand, efficient techniques are usually indirect. Thus, democratic techniques are dialogue intensive, whereas technocratic techniques rely on feed forward and feedback. Computer-based polling techniques in face-to-face meetings offer some promising new approaches that are both democratic and efficient. This technology-augmented meeting procedure gives all participants equal opportunity to anonymously register their opinions and get immediate feedback on the opinions and attitudes of the entire group. When facilitated by a skilled moderator, this approach enables rapid appraisal of consensus and disagreement, identifies additional information needs, permits discussion of controversial issues without intimidation, and rapidly establishes priorities (21).

There is also a basic dichotomy between structured and unstructured techniques of community interaction. Techniques that are democratic but are still overlaid by a structure could achieve greater democratic efficiency. Task forces and group process are two techniques that readily come to mind.

Scheduling

Finally, we arrive at the biggest challenge suggested by this analysis: making quick decisions that are somehow based on thorough evaluations that meet legitimate community concerns. Based on my own research in Seattle, I strongly suggest that planning studies not take more than one year (1). This is an immense challenge, but citizens, and sometimes planning staffs, burn out and lose their enthusiasm after this period of time.

CONCLUSIONS

Through application of the concept of democratic efficiency, this paper suggests a number of approaches to resolving the dilemmas posed by the desire to achieve both democracy and efficiency in citizen-participation processes. Substantial gains in democratic efficiency can be achieved by making modest increases in planning and administrative budgets for staff training, technical assistance for community groups, meeting preparation, and citizen participation in the design and implementation of citizen-participation processes.

By broadening the diversity and scope of agency resources used to complement volunteer citizen resources, the level of citizen frustration that is often associated with democratic but poorly facilitated planning processes can be reduced. Expenditure of these resources should yield public benefits by reducing delays in implementation at the end of the planning process, since the resulting decisions will be built on a solid base of citizen support. Without citizen support, transportation plans are nearly impossible to implement. And while planners scramble to build a constituency that could have been developed earlier through a properly conceived and implemented citizen-participation program, transportation capital and operating costs inflate rapidly, and corridors with uncertain futures suffer severe adverse economic and social impacts. It may be more cost effective in the long run to spend the resources to do citizen participation right the first time around.

In summary, our substantive knowledge about the effectiveness of citizen participation is still quite primitive. Since the costs of citizen frustration and delayed decisions are high, we cannot afford to be complacent that our current approaches and techniques are adequate. If we are to learn which approaches are truly effective, more evaluation studies that monitor citizen-participation processes from beginning to end are needed (22). We also need citizen participation in evaluating the effectiveness of citizen-participation programs, since approaches that achieve agency goals but frustrate citizen goals are not truly effective.

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Abridgment

Transportation Investment in Less-Developed Countries: The Case of Guyana

G. Budhu and A. G. Hobeika

The procedure of incorporating the transportation variable in determining the effect of transportation investment for low-volume roads is generalized and applied to regions in Guyana where water is the only mode of transportation. Several regions in Guyana that have poor means of access are known to have characteristics similar to developed regions of the country that have "efficient" modes of transportation. Yet these regions remain sparsely populated and relatively underdeveloped. Previous studies that have used the traditional approach of quantifying benefits against costs have always concluded that transportation investment was infeasible in such regions. The economic activities and constraints of the Berbice-Orealla region of Guyana are formulated into a linear programming model to determine the net economic effect of transportation investment in the region. The analysis shows that the benefits of improved transportation for the region exceed the costs. Application of the model to other

less-developed regions would assist in priority ranking of transportation investments in less-developed countries. Various criticisms and attributes of the model are also discussed.

Transportation in a developing country is fundamentally the same as transportation anywhere else. However, there are special problems and impacts that deserve separate consideration.

In advanced countries, transportation development takes place largely because of a demand that is already there. In developing countries, transportation acts as a catalyst to the development process. The provision of new transportation services is in itself an important factor in increasing the demand. This implies a planning approach that looks not only at the transportation system itself (in terms of capacity) but also at the processes of production and distribution that the transportation system has to serve.

Planning presupposes the establishment of certain goals and objectives and the outlining of strategies to achieve these goals and objectives. In most less-developed countries, the planning phase of transportation is more or less nonexistent in regions that have poor accessibility. Transportation projects tend to move directly into the implementation stage because of (a) ad hoc political decisions, (b) an intuitive "feel" for what is supposedly required, (c) a supporting connection to other activities, and (d) the high costs of the selection process, i.e., feasibility studies.

THE PROBLEM

Very few productive activities are carried out in the less-accessible regions of a country. As a result, the transportation traffic generated by these regions along rivers or trails is very low. The low volume of traffic, in terms of frequency or ton kilometers, tends to immediately point to the infeasibility of improved access (based primarily on traffic benefits). Moreover, there is generally a lack of applied inexpensive methodologies for quantifying the developmental effects of transportation in less-developed regions, where resources released through improved transportation contribute to increased production in the region. In addition, most engineers are very conscious of the time and costs involved in feasibility studies. This initial (feasibility) cost weighs against transportation projects in regions of low traffic volume and thus influences the decision maker to move directly to the implementation stage or reallocate the money to high-volume roads.

The above situation points to the need for an inexpensive methodology for prioritizing the many requests for improved transportation in regions with poor accessibility.

STUDY OBJECTIVE

The main objective of this study is to provide an inexpensive methodology that

1. Determines the net effect of improved transportation (i.e., the supply of transportation) on the economy in poorly accessible regions in less-developed countries and
2. Assists in project selection, i.e., ranking of projects in terms of their net benefits and costs of investment in the transportation infrastructure.

The methodology is carried out by using a linear programming technique based on data from a relatively inaccessible region in Guyana.

MODEL FORMULATION

Transportation affects and is affected by the main activities of a region; i.e., transportation competes with the other activities of a region for the available resources. Thus, it is necessary to incorporate the transportation activity in the model and to study its effects on the other main economic activities. The inclusion of the transportation activity allows for the analysis of the explicit effects of improved transportation on the region's economic growth.

The following minimal information is required to formulate the linear programming model (since the model is formulated in U.S. customary units of measurement, no SI equivalents are given):

1. Area of influence—The acreage currently served by the present mode of transportation and the increased area of influence given improved transportation;
2. Key activities—The main activities, including transportation, that make up the economy of the area of influence, such as agriculture, dairy farming, logging, and mining;
3. Available resource—The total amount of resources available to the region for carrying out its main economic activities, e.g., labor, available land, and equipment;
4. Input coefficient—The quantity of each available resource required to produce one unit of the key activities; and
5. Output coefficient—The amount of net earnings each unit of output of the main activities contributes to the economy.

The model is formulated as follows: Maximize

$$z = C_i X_i + C_t Y_t \tag{1}$$

subject to

$$AX_i + DY_t \leq B_i \tag{2}$$

$$FX_i - GY_t = 0 \tag{3}$$

$$X_i, Y_t \geq 0 \tag{4}$$

where

- C_i = net contribution to the economy of one unit of the main activities of the region;
- X_i = a unit of the main activities in the region (i = 1, . . ., n; n = number of activities except transportation);
- C_t = net contribution of one unit of the transportation activity;
- Y_t = a unit of the transportation activity for the mode under consideration;
- A = input coefficients in terms of time, person hours, and materials, etc., or the amount of resources consumed by unit measure of each activity in the region;
- D = input coefficients of resources consumed by one unit of the transportation activity under consideration;
- B_i = maximum available resources in the region;
- F = demand coefficient for transportation by the economic activities of the region (ton-miles); and
- G = supply coefficient for transportation by the transportation activity of the region (ton-miles).

Figure 1. Description of the production condition without any investment (base scenario condition).

Input Coefficients	Activities x_1	x_2	x_3	x_4	x_5	Available Resources $[B_i]$
Unskilled Labor (Man-hours)	200	80	350	300	90	9,000,000
Skilled Labor (Man-hours)	3	5 [A]	-	-	- [D]	200,000
Tractors (Machine-hours)	3	5	-	-	-	120,000
Cattle Land (Acres)	-	-	4	-	-	50,000
Farm Land (Acres)	1	1	1	1	-	55,000
Transport (Ton miles)	-	40 [F]	50	156	150 [G]	
Output Quantity (lbs; ton-miles)	6,000	1,800	(Milk) 2,000 (Meat) 200	7,000	150	
Value Added (G$)	150	150	[C_i] 300	200	15 [C_t]	

Equation 1 is the objective function that the model optimizes. Transportation, like any other activity, contributes to the region's output, and so it is included in the objective function at a positive level. Equation 2 is the constraint equation that guarantees that no more than the available resources can be consumed. Equation 3 is the equilibrium equation; i.e., the demand for transportation by all the activities must be balanced by the supply of transportation. An optimal solution occurs when the demand for transportation equals the supply; i.e., the quality and level of transportation influence the total net benefits of the region. Equation 4 guarantees no negative outputs by any of the activities.

APPLICATION OF THE MODEL TO GUYANA

In several regions of Guyana today, the only means of transportation is small boats owned and operated by the farmers who live in these regions. When one looks at maps of Guyana, one can see that development, in terms of the intensity of cultivation and population density, stops dramatically at the end of accessible roads. Certain regions in Guyana have remained "static" over the years even though they have much the same soil and water potential as other areas that have efficient transportation. Over the years, repeated requests for improved transportation in these regions have been rejected on the grounds of infeasibility, primarily based on present and projected traffic volumes.

The linear programming technique is used here to evaluate the overall impact of improved transportation in these regions of Guyana. The net benefits with and without improved transportation are then used to determine the feasibility and priority ranking of transportation projects.

Prototype Model

The prototype model will be formulated, analyzed, and presented for the Berbice-Orealla region in Guyana. However, before priority ranking is done, similar analyses should be carried out for all regions that request improved transportation.

The Berbice-Orealla region currently has five main activities, including transportation by water. The inputs to the linear programming model are as follows (since the model is formulated in U.S. customary units of measurements, no SI equivalents are given):

X_1 = subsistence agricultural farming, such as vegetable cultivation, poultry farming, and cash crops, carried out to satisfy family needs only (acres);
X_2 = rice farming (acres);
X_3 = cattle farming (acres);
X_4 = banana cultivation (acres);
Y_t = X_5 = transportation (ton-miles);
B_1 = unskilled labor (person-h);
B_2 = skilled labor (person-h);
B_3 = tractors (machine-h);
B_4 = cattle farm land (acres); and
B_5 = agricultural farm land (acres).

The input and output coefficients, the maximum available resources, the profitability, and the constraining equation of each of the economic activities were determined for the base condition for the region. These values are summarized in Figure 1.

Figure 1 shows the input matrix coefficients for X_1, X_2, X_3, X_4 [A]; the input column-vector coefficients for the transportation activity X_5 [D]; the transportation demand coefficients for the other economic activities [F] and the transportation supply coefficients [G]; the available resources in the region [B_i]; and the net contribution coefficient for each key activity [C_i] and [C_t].

The linear programming formulation for the base scenario is as follows: Maximize

$$z = 150X_1 + 150X_2 + 300X_3 + 200X_4 + 15X_5 \tag{5}$$

subject to

$$200X_1 + 80X_2 + 350X_3 + 300X_4 + 90X_5 \leq 9\,000\,000 \tag{6}$$

$$3X_1 + 5X_2 \leq 200\,000 \tag{7}$$

$$3X_1 + 5X_2 \leq 120\,000 \tag{8}$$

$$4X_3 \leq 50\,000 \tag{9}$$

$$X_1 + X_2 + X_3 + X_4 \leq 55\,000 \tag{10}$$

$$40X_2 + 50X_3 + 156X_4 - 150X_5 = 0 \tag{11}$$

where $X_1 \geq 0, X_2 \geq 0, X_3 \geq 0, X_4 \geq 0, X_5 \geq 0$.

The following assumptions and explanation will assist in understanding the formulation of the model.

1. The model assumptions are that (a) there is a guaranteed market for all produce; (b) the output of subsistence agriculture is not transported, since by

definition this is farming done for family living and therefore the output is consumed within the region of influence; and (c) the maximizing equation, or z-value, is over the crop cycle (i.e., in a one-year period the region's total net dollar value is equal to the value of z in dollars).

2. The regional market for all produce is 25 miles away by river to the center of gravity of the region of influence.

3. A typical explanation of the coefficients in Figure 1 would be, for example, for X_2 (rice farming), one unit (1 acre of rice-farming activity) consumes 80 unskilled person-h, 5 skilled person-h, and 5 machine-h and produces 1800 lb of rice, which earns a net profit of $150 and requires 40 ton-miles of transportation to the market.

Investment in Transportation

To study the effect of transportation investment in the region, we reformulate the model by taking into consideration transportation investment in roads. Investments in roads and trucking will affect the transportation activity X_5 and result in changes in the input coefficients of the column vector D and row vector F, as follows:

1. Transportation activity X_5, column vector D, now requires 4 person-h of unskilled labor, 2 person-h of skilled labor, and 2 truck-h to provide one unit of transportation.
2. Transportation requirements X_2, X_3, and X_4, row vector F, now require 33, 40, and 127 ton-miles, respectively, of transportation to the market by road.

Solution of the Models

The model for both the base scenario—that is, without any investment in transportation—and for investment in roads resulted in the following net benefits per year:

1. Given no investment in transportation, the region would provide a net benefit of $8 469 000/year.
2. Given investment in roads, the region would provide a net benefit of $9 351 000/year.

Transportation investment has thus increased the region's net benefit by $882 000/year.

SENSITIVITY ANALYSIS

Both the availability and the accuracy of data in less-developed countries are subject to doubt. The linear programming technique allows quick checks to be made on such suspect data.

The effect of varying the transportation coefficient D—i.e., the efficiency of available water transportation—is given in the table below:

Coefficient	Net Benefits ($)
90	8 469 000
75	8 599 000
60	8 740 000
45	8 894 000

If water transportation can be improved to the point where it only consumes 45 person-h for the 150 ton-miles of transportation, then the net benefits z of the region will be increased from $8 469 000 to $8 894 500/year for the base-case condition.

Sensitivity analyses were also carried out on the other key input and output coefficients and available resources of the region but are not presented. The insights obtained from these analyses (for example, dramatic shifts in cultivation patterns that would not normally occur in real life because of the cost involved in farmland conversion) led to the reformulation and extension of the model to reflect these constraints.

REFORMULATION AND EXTENSION

The linear programming model was reformulated to allow for cultivation of minimum acreages in the main agricultural activities, and additional constraints were introduced to account for inputs of fertilizer and improved transportation by road. The effect of improved transportation and the use of fertilizer led to almost a doubling of the net benefits of the region.

FEASIBILITY AND RANKING

The traditional cost-benefit analysis was carried out for the provision of a low-volume road into the region in question. The analysis showed that the benefits of improved transportation for the region exceeded the costs incurred. In a similar manner, the socioeconomic characteristics of other regions that have poor accessibility can be formulated and cost-benefit analyses carried out. Then the final ranking for project funding can be determined by using both the benefit/cost values and such other factors as connectivity, availability of other modes of transportation, administration, defense, and desired national goals.

DISCUSSION OF THE MODEL

Certain criticisms of the model can be answered as follows:

1. The transportation activity is aggregated into one variable measured in ton-miles, and it could be said that this aggregation is not realistic because other factors, such as quality of service and cost, affect transportation. Partial consideration is given to cost in the C_t coefficient, and time consumed by mode is reflected in the constraint equations. However, since ton-miles is a significant measure of the economic need for transportation in less-developed regions, the aggregation is not oversimplistic for the level of analysis used.
2. The model is a static model—i.e., there is no feedback from the variables. This aspect can be modified by considering smaller time blocks, i.e., five years, as the analysis period. For a short analysis period, new and more accurate input and output coefficients can be used. Even the criticism of a fixed coefficient for what is essentially a dynamic situation will also be partly overcome by using the appropriate formulation.

The strengths of the model are the following:

1. The model does assign a monetary value to the impact of improved transportation on the economy of the region.
2. A modest amount of data is required to formulate and analyze a given scenario.
3. Sensitivity analyses can be performed on "poor" data.
4. There is the possibility of explicitly including policy decisions in the model.
5. The technique can be taught and carried out for very little cost and time at local decision-making levels.
6. The model does reduce dependence on intuition

for what is supposedly the "best" transportation solution.

7. The model does provide some indication as to what might be the optimal output of a region given the efficient allocation of resources.

CONCLUSIONS

The linear programming technique can be used to provide a quick and reasonably accurate solution to the possible net dollar effect of transportation investment in regions that have poor accessiblity. In situations where the number of requests for improved transportation far exceeds the allowable transportation budget, the techniques can be used, in combination with other "goal-oriented" techniques, to establish a financially feasible list of projects.

Transportation investments in inaccessible regions that would normally be considered infeasible based only on quantifiable benefits attributable to traffic volumes can be assessed by the model for their true effects on a region.

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Relating Vehicle Use to Highway Characteristics: Evidence from Brazil

Robert Harrison and Joffre D. Swait, Jr.

Data derived from a large-scale user-cost survey currently being conducted in Brazil are presented and analyzed. Equations for six vehicle classes that are used to predict rates of vehicle use (defined as kilometers traveled per month) as a function of highway characteristics are presented. The highway characteristics studied are surface roughness and three measures of vertical geometry. These data were collected by two specially instrumented vehicles that measured a network of 597 routes totaling 38 000 km. Vehicle-use data representing 1220 vehicles were used as the main analysis set; the set comprised 265 cars, 57 utility vehicles, 655 buses, and 243 trucks. A further 261 heavy vehicles were used to derive predictions for this class after the main analyses had been conducted. Equations derived from the analyses were tested against a further set of 145 vehicles. Reference to previous studies is made, and an example that shows the derivation of differential depreciation costs per kilometer is included. Preliminary results on the effect of vehicle age are given, and details of further work are specified.

Vehicle use is an important component in the economic evaluation of highway construction and maintenance policies. It permits vehicle operating costs to be calculated on a lifetime, annual, or kilometer basis as well as directly influencing time-related benefits such as depreciation, interest, crew costs, and the value of passenger time. Therefore, total user-cost differentials attributable to alternative construction and maintenance policies are significantly influenced by decisions made about the appropriate levels of vehicle use. There has not been extensive primary research into levels of vehicle use, despite their importance, and estimates of use normally involve assumptions that are difficult to substantiate.

The earliest-reported information on the effects of road surface type on vehicle operating cost and use was developed at Iowa State University in 1939 by Moyer and Winfrey (1) based on a survey of vehicles used as rural mail carriers. Moyer and Winfrey showed that the use of a vehicle decreased with age and that annual vehicle mileage increased substantially as a higher percentage of vehicle operation switched to paved or gravel roads from earth roads.

The results of a survey carried out in Africa by Bonney and Stevens (2) provided additional information on differential rates of vehicle use for vehicles operating on different types of surfaces. The results were based on 65 passenger and freight vehicles operating over 27 routes of different types over a period of two years. Routes were grouped into three major types: bituminous, improved gravel, and unimproved gravel. The results clearly show differential rates of use among the three types of routes, which enabled Bonney and Stevens to derive depreciation costs per kilometer for each surface category.

Predictions of vehicle operating costs were published in 1975 as a result of the Transport and Road Research Laboratory (TRRL) study in Kenya (3) but, although the calculation of depreciation required annual vehicle use as an input, it was derived exogenously and not predicted from user data (3, p. 62). The results of the Kenya user survey were subsequently modeled (4), and vehicle use was derived from the product of vehicle speed and estimates of hours driven. This approach is widely used—for example, in the World Bank's Highway Design and Maintenance (HDM) model (6)—and justifies careful examination.

Highway characteristics are generally considered to affect vehicle use through changes in speed. Variations in surface condition (such as roughness) or geometric design (such as vertical profile) alter the speed at which a vehicle can be driven, and estimates of use can be derived by multiplying average speed by hours driven. Although average speed can be accurately determined from the data available on this subject, the analyst is forced to make assumptions about hours driven. Sometimes the average number of hours driven per vehicle is considered a constant, so clearly use varies proportionately with speed. However, although an increase in vehicle speed should generally lead to a greater number of trips being undertaken, nondriving time will also increase so that the effect on use is probably less than proportional. The analyst must make judgments about what is appropriate based on very few data. The broad choices that are available are described in the user's manual to the World Bank's HDM model (6).

The difficulties inherent in estimating hours driven are highlighted by remembering that the commercial vehicle operators who constitute the majority of users on highways in developing countries should be viewed as rational, profit-seeking individuals. They will try to minimize their costs with respect to changes in highway characteristics. Some of the factors that influence their cost structure are cargo value, customer requirements, crew costs, and route length. A deterioration in surface condition that results in a reduction in vehicle speed might well, in certain cases, be fully compensated for by users proportionally increasing their hours driven to maintain constant use. The situation is clearly rather complex. Since reliable data on hours driven are sparse and relations between hours driven and highway characteristics are entirely absent from the literature, hours driven should be used with care.

However, if data on vehicle use are collected directly from road users and then related to highway characteristics, problems over hours driven are avoided. The product of speed times hours driven appears on the vehicle odometer, which provides the data record, and rational decisions made by operators with respect to changes in highway characteristics are subsumed. Vehicle use can be simply determined without making any assumptions about hours driven. It was decided to test this approach in Brazil. Since no literature exists that directly links vehicle use with highway characteristics, this constituted a first attempt at estimating vehicle use in this manner.

BACKGROUND OF THE PROJECT

The government of Brazil and the United Nations Development Program are currently sponsoring a major research project to determine the interrelationships in Brazil between the costs of highway construction, maintenance, and use. The Brazilian Ministry of Transport provides management to the project through a related organization, the Empresa Brasileira de Planejamento de Transportes (GEIPOT). Technical assistance is provided by the staff of the Texas Research and Development Foundation. The World Bank acts as the executing agency for the United Nations Development Program, and the research is based at the headquarters of GEIPOT in Brasilia. The research began in September 1975, the first phase terminated in November 1979, and work is continuing in 1980.

The central objective of this project is to assist the government of Brazil in minimizing the total cost of its highway network by making possible thorough and rapid evaluations of alternative highway strategies. This requires that individual relations for the three components of construction, maintenance, and user cost first be developed and then be combined in a computer model. The relations between user costs and highway characteristics are important because benefits attributable to improvements are largely composed of reductions in user costs.

User costs were related to highway characteristics through a series of experiments and surveys. In the surveys, vehicle operators' cost records were examined. These surveys were particularly important because the majority of user-cost components could not be experimentally determined from the available resources. Vehicle use, defined as kilometers traveled per month, was included in the surveys to provide an input to the calculation of vehicle depreciation and interest. This paper briefly describes the data-collection techniques used, presents predictions of use for five vehicle classes (specifying vehicle use as a function of pavement roughness and various highway geometry measures), and discusses the implications of these results.

COLLECTION OF DATA ON VEHICLE USE AND ROUTE CHARACTERISTICS

The wide range of procedures and skills necessary for the efficient collection and analysis of data on vehicle operating cost from company records required the formation of a specific team, the User Costs Surveys Group, within the structure of the Brazil study. The broad objectives given to this team required data on operating cost to be associated with quantifiable road characteristics so that cost differentials, attributable to changes in highway characteristics, could be determined. Data on vehicle operating cost collected by the group were first assigned to routes. Then, before analysis could be undertaken, the characteristics of these routes had to be determined. Route data were collected by using two specially designed survey vehicles instrumented and serviced by project staff.

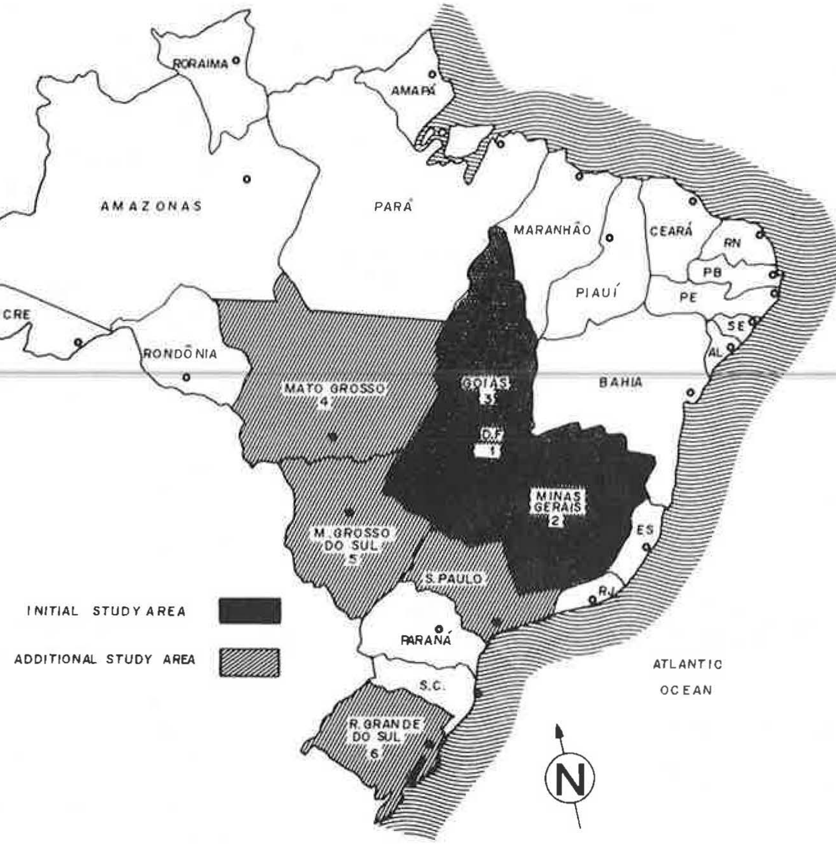
Collection of data on vehicle operating cost was initially concentrated in the states of Minas Gerais and Goiás and in the Distrito Federal (see Figure 1). The major proportion of the vehicles recruited for the survey derived from these regions, but it became necessary to supplement these vehicles with others operating in states with different geographic features to ensure that the greatest possible range of highway characteristics was covered for analysis. Accordingly, vehicle data were collected in Mato Grosso, Rio Grande do Sul, and São Paulo. The survey vehicles collected 85 000 km of geometry and roughness data to produce highway characteristics for the network of routes used by the vehicles in the survey.

Data on operating cost were collected by the field research staff, who made regular, usually monthly, visits to each participating company. The data were subject to various edits and checks before being stored on computer file. Vehicle use was defined and recorded as the average number of kilometers traveled by a vehicle per month and was based on an average data period of 16 months for vehicles in the main survey. This period was considered perfectly adequate, particularly as it covers all the seasonal changes that might be expected to influence vehicle use. Fuel consumption per kilometer was used as a check on the recorded data on vehicle use.

Data were collected on more than 1500 vehicles that represented more than 100 companies and a wide range of vehicle makes and models. The individual vehicles were grouped into five classes: commercial automobiles, utility vehicles, buses, medium trucks, and heavy trucks. Details of these classes are shown in Figure 2. It will be noted that utility vehicles is a very broadly defined class that incorporates different vehicle types. This class was studied because dual-purpose vehicles (such as pickups) and light trucks form a significant traffic group on low-volume roads. Despite the problems that such amalgamation causes, it was considered worthwhile to attempt to estimate the patterns of use for such vehicles. Very few private automobiles were registered in the survey, and few reliable data were available for analysis. Although commercial automobiles achieved levels of use that were considered inappropriately high for private automobiles, it was decided to analyze this class to see if any useful data could be obtained that could subsequently be used for modeling private-automobile use. The main survey data were supplemented by a special study on the use of heavy trucks to ensure that this class was not underrepresented.

Two specially instrumented cars were fabricated by the project staff to rapidly measure the characteristics of operators' routes identified in the main survey. The

Figure 1. Study area for user-costs survey.



survey-vehicle instruments are shown in Figure 3. The road-roughness-measuring system consisted of a Mays road meter and an accurate odometer, the distance-measuring instrument (DMI) (7). These instruments combined to form the "Maysmeter" system, which, when in operation, produced a count every 320 m. The system was maintained in strict calibration with an established roughness base, here provided by the GM Profilometer and its Quarter Car Simulator (8). Each vehicle was regularly checked by correlating the output of the Maysmeter system with roughness numbers produced by the Quarter Car Simulator on profiles recorded by the Profilometer as the vehicle traveled over a special calibration course. This correlation produced roughness values in units referred to here as QI* counts per kilometer. QI* is the unit of roughness analyzed in this paper.

To rapidly measure the vertical profile of a route, it was necessary to develop a device that could identify grade changes from a moving vehicle. Several instruments were evaluated, and an electronic accelerometer connected to a panel meter and designed to display grade measurements up to ±12 percent was finally selected. Horizontal measurements were obtained by using a standard aircraft-type directional gyro compass (7) and the DMI. The start and finish of the curve were identified by the driver, and the operator noted its direction and length.

All vehicle-use and route data were screened before analysis; 1220 vehicles comprising 265 cars, 57 utility vehicles, 655 buses, and 243 medium trucks were used as the main analysis set. A further set of 145 vehicles was reserved as a verification set to test the equations derived from the main analyses. Heavy vehicles (40-t gross vehicle weight) were poorly represented in the main file, and no data were available for analysis. A supplementary study was undertaken to collect more data for this important vehicle class.

DEPENDENT AND INDEPENDENT VARIABLES

The factorial shown in Figure 4, which was used to direct and manage the data-collection effort, shows the dispersion of vehicles used in this analysis. The generic classifications defining each of the cells were quantified at the start of the analysis in terms of the geometry and roughness measures selected as the independent variables. All subsequent references to "cell" refer to the factorial partitions shown in Figure 4 (figures in parentheses show the number of company means per vehicle class).

The data-collection procedures located companies that operated in the various cells of the factorial, in an effort to ensure a good spread of data. Each company was evaluated and, where appropriate, vehicles were selected for inclusion in the survey for a period sufficient to establish estimates of the various user costs. Dependent data can therefore be considered at either the company or the vehicle level. The companies can be seen as constituting the sampling units, that is, the units from which inferences can be drawn, whereas the vehicles are the observation units used to obtain the actual vehicle operating information. These definitions are significant because probability statements, in the form of confidence intervals for predictions, must be based on the unit on which the inferences are drawn—the company. As noted before, the dependent variable, vehicle use, was defined as the average kilometers traveled per month during the survey period.

The extensive inventory of user routes permitted a series of geometric indices to be examined for their explanatory power with respect to vehicle use. Indices were constructed for both vertical and horizontal geometry, and an attempt was made to correlate both with the dependent variable. However, because of multicollinearity, it was not possible to perform an analysis that used both types of measures. This is not really surprising when one considers that terrain requirements often force a degree of correlation between vertical profile and horizontal alignment on the highway planner: Flat roads are often straight, whereas mountainous roads tend to have many curves. The preliminary analysis, therefore, concentrated on measures of vertical geometry, since this was known to exert a greater influence on speed and hence on use.

Three measures of vertical geometry are reported in this paper:

1. Rise plus fall (RPF), in meters per kilometer, has been used in a previous study (3) as an independent variable to explain variations in fuel consumption, vehicle speed, and so on. The following approximate formula can be used to calculate this index:

$$RPF = \sum_{i=1}^{n} |g_i| l_i / 100 * \sum_{i=1}^{n} l_i \quad (1)$$

where

g_i = i th grade value (i = 1, . . ., n) (%),
l_i = length of i th grade (km), and
$|\cdot|$ = absolute value.

Intuitively, this index can be understood to substitute for the real vertical profile of an equivalent roadway that has a mean percentage grade of (RPF/10).

2. One can use a percentage measure of mean grade (MG) derived from a grade distribution, as follows:

$$MG = (C_1 + 3.6C_2 + 5.6C_3 + 7.6C_4)/100 \quad (2)$$

where

C_1 = precentage of route length whose grade is from -3 to +3 percent,
C_2 = percentage of route length whose grade is between -3 to -5 percent and +3 to +5 percent,
C_3 = percentage of route length whose grade is between -5 to -7 percent and +5 to +7 percent, and
C_4 = percentage of route length whose grade is from ≥-7 to ≥+7 percent.

Figure 2. Vehicle classes used in main survey.

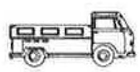
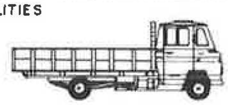
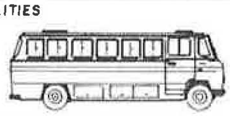
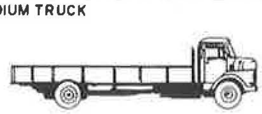
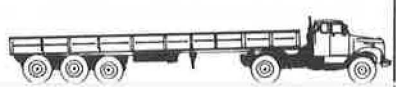
TYPE	CLASS	REPRESENTATIVE VEHICLE CHARACTERISTICS
CAR 	1	GROSS WEIGHT - 1 T 46 BHP (DIN) GASOLINE 4 CYLINDER
UTILITIES 	2	GROSS WEIGHT - 2.7 - 3.3 T LOAD 1.2 - 2.2 T 133 BHP (DIN) GASOLINE 4 CYLINDER
UTILITIES 	2	GROSS WEIGHT - 6 T LOAD - 4 T 98 BHP (DIN) DIESEL 4 CYLINDER
UTILITIES 	2	GROSS WEIGHT - 6T LOAD - 2 T 98 BHP (DIN) DIESEL 4 CYLINDER
BUS 	3	GROSS WEIGHT - 11 T LOAD - 4 T 130 BHP (DIN) DIESEL 6 CYLINDER
MEDIUM TRUCK 	4	GROSS WEIGHT - 15 T LOAD 8 - 10 T WITH THIRD AXLE, GROSS WEIGHT - 22 T LOAD 13 - 15 T 130 BHP (DIN) - DIESEL 6 CYLINDER
HEAVY TRUCK 	5	GROSS WEIGHT - 40 T LOAD 24 - 28 T 275 BHP (DIN) DIESEL TURBOCHARGED 6 CYLINDER

Figure 3. Specially instrumented survey vehicle.

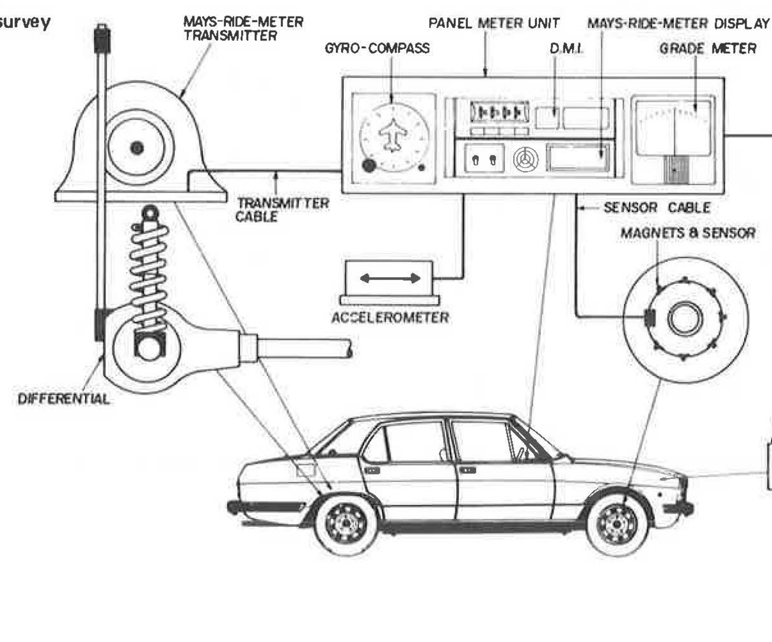


Figure 4. Factorial of distribution of vehicle classes by road-geometry and roughness measures.

SURFACE TYPE	HORIZONTAL	VERTICAL: FLAT	ROLLING	HILLY
PAVED	1	Cars 1 (1) Utilities 10 (1) Buses 58 (4) Trucks 2 (1)	Cars 82 (3) Utilities 13 (4) Buses 160 (13) Trucks 92 (9)	Cars 6 (2) Utilities 3 (2) Buses 28 (2) Truck 1 (1)
PAVED	2	Cars 3 (3) Buses 13 (2)	Cars 68 (4) Utilities 1 (1) Buses 22 (6) Trucks 3 (1)	Cars 35 (2) Trucks 20 (4)
MIXED	1	Buses 4 (1) Trucks 2 (1)	Cars 10 (2) Utilities 2 (1) Buses 47 (10) Trucks 47 (3)	Car 1 (1) Utilities 1 (1) Buses 2 (1)
MIXED	2	Car 4 (1)	Cars 21 (2) Buses 4 (2) Trucks 10 (6)	Cars 19 (2) Buses 3 (2) Trucks 3 (2)
UNPAVED	1	Utilities 1 (1) Buses 96 (7)	Cars 6 (2) Utilities 6 (1) Buses 150 (9) Trucks 4 (2)	Utilities 1 (1) Buses 4 (2) Trucks 38 (24)
UNPAVED	2	Buses 8 (1)	Cars 7 (2) Utilities 6 (6) Buses 38 (9)	Cars 2 (2) Utilities 13 (11) Buses 18 (7) Trucks 21 (3)

HORIZONTAL 1 = STRAIGHT, 2 = CURVY

The constants in Equation 2 represent midpoints of the distribution of grades.

3. A measure of extreme geometry (EG), derived from a grade distribution, can be used. This index, in percent, is defined as

$$EG = G_1 + G_2 \qquad (3)$$

where G_1 = percentage of route length whose grade is $\geq$-5 percent and G_2 = percentage of route length whose grade is $\geq$+5 percent.

The roughness measure QI*, used to characterize the quality of the riding surface, was derived from data collected in 320-m intervals by the survey vehicles. To describe the roughness of a route as determined by these measurements, a summary statistic was necessary. The following procedure was used:

1. The roughness measurements were sequentially examined and grouped into homogeneous bands in accordance with acceptable variance levels established through tests on both paved and unpaved sections.
2. An average roughness for the route was calculated as the weighted average of the means of the homogeneous bands, by using the band lengths as weight.

To better characterize the various geometry measures, the table below gives the ranges of each measurement found for the general classifications of flat, rolling, and hilly terrain on the routes surveyed by project vehicles:

Measure	Flat Terrain	Rolling Terrain	Hilly Terrain
RPF (m/km)	5-24	14-37	29-52
MG (%)	1-2	1.5-3	2.3-4.5
EG (%)	0-10	3-30	10-54

For the same routes, the roughness measure QI* produced the following values for various surface types:

Surface Type	QI* (counts/km) Mean	Minimum	Maximum
Paved	43	21	159
Mixed	84	25	157
Unpaved	145	41	265

Several statistics for the geometry and roughness data used in the analysis that assist in defining the inference space are given below:

Variable	Mean	Standard Deviation	Minimum	Maximum
R	90.92	56.92	22.00	203.00
RPF	30.39	7.08	8.00	48.00
MG	2.47	0.57	1.00	3.87
EG	18.81	10.94	0.00	43.52

Table 1. Regression equations for vehicle use as a function of highway characteristics.

Geometry-Measure Variable	Intercept	C_2	C_{34}	C_5	Geometry Measure	Q	QXC_{345}	A	S_e^2	R^2
RPF	9.729	-0.314	-0.251	-0.213	-0.001 93	-0.007 52	0.004 85	-0.0594	0.480	0.52
	(0.12)	(0.11)	(0.09)	(0.13)	(0.003)	(0.003)	(0.001 4)	(0.0094)		
MG	9.757	-0.316	-0.252	-0.164	-0.056 7	-0.007 55	0.004 84	-0.0594	0.478	0.52
	(0.12)	(0.11)	(0.09)	(0.13)	(0.037)	(0.001 3)	(0.001 3)	(0.0094)		
EG	9.721	-0.325	-0.261	-0.120	-0.004 39	-0.007 51	0.004 84	-0.0591	0.470	0.53
	(0.09)	(0.11)	(0.09)	(0.13)	(0.002 0)	(0.001 3)	(0.001 4)	(0.0093)		

Note: All regressions are based on 194 means. Figures in parentheses are the standard errors of the coefficients. Base vehicle class is that of commercial automobiles (i.e., $C_2 = C_{34} = C_5 = C_{345} = 0$). The weight used is the number of vehicles observed in the highway-characteristic/company cell combination.

These statistics are very important in determining the robustness and wide applicability of the relations presented.

ANALYSIS AND RESULTS

An analysis of variance performed on the analysis set showed that the variance of vehicle use between companies in a cell was significantly larger (approximately seven times) than that between vehicles in a company. This is probably attributable to unmeasured effects of company policy, such as the choice of vehicle, and thus to the company's performance characteristics, customer needs, and managerial efficiency. In view of the previous comments on sampling and observation units, one would expect greater homogeneity between vehicles in the same company (sampling unit) than between different companies within a cell. The broad choices for analysis narrowed down to individual vehicles or companies; both were evaluated, and the latter are reported in this paper. It was decided to aggregate company vehicles in each cell to produce a company-cell mean for each company in each cell. Company-cell means were preferred because they enabled the analyst to comprehend more of the statistical influences, especially those related to policy effects. Furthermore, at the company-cell level, the ranges of independent variables were broader because the survey methodology placed great importance on selecting vehicles that operated on homogeneous route types (hence, relatively narrow ranges).

All of the vehicle data for each company in each cell were aggregated, and means were derived for both dependent and independent variables. If a company had vehicles operating in more than one cell, means for each cell were calculated by using the company vehicles operating in the cell. The 1220 individual vehicles in the analysis set resulted in 194 company-cell means.

By using the data for commercial automobiles, utility vehicles, buses, and medium trucks, the effect of surface condition (roughness) and vertical geometry on vehicle use was estimated by means of weighted least squares, the weight being the number of vehicles within each company-cell mean. The regression analyses resulted in the formulas given in Table 1, where

C_2 = 1 if utilities, 0 otherwise;
C_{34} = 1 if buses or medium trucks, 0 otherwise;
C_5 = 1 if heavy trucks, 0 otherwise;
C_{345} = 1 if buses or medium or heavy trucks, 0 otherwise;
Q = road roughness (QI* counts/km);
A = vehicle age (years);
R^2 = coefficient of multiple determination; and
S_e^2 = standard error of the equation.

The log-linear form of the model is reported because the hypothesis of homogeneity of variance across factorial cells is rejected at the $\alpha = 0.001$ level and so some form of transformation—such as log linear—is desirable.

The heavy-vehicle supplementary study yielded data on 261 vehicles, which constitute 15 company-cell means. Heavy vehicles rarely operate regularly on unpaved routes, and the narrow range of roughness associated with the observations caused difficulties in the main analysis. These vehicles were therefore excluded from the analysis set and reintroduced in the final stages of the analysis to provide a usage estimate. This was done by calculating the mean use for paved, rolling highways and adjusting the intercept of the equation by assuming that the effect of highway characteristics on heavy-truck use is the same as that predicted for medium trucks.

The adjusted equation for heavy trucks gives good predictions for paved roads (< 50 QI*), but extrapolation to levels of roughness for mixed and unpaved highways should be done with caution. It is likely that, if heavy trucks were used regularly on unpaved routes, they would show levels of use similar to those of medium trucks and not as high as those predicted. It is recommended, therefore, that the heavy-truck equation not be used where highway roughness exceeds 50 QI* and that, where predictions of use on unpaved routes are required, the medium-truck equation be used.

The equations in Table 1 show roughness as a significant main effect. This paper is the first in the literature to demonstrate such a link between vehicle use and road-surface condition (roughness). Use of a vehicle such as a medium truck decreases by 30 percent if it operates in Brazil on an average unpaved route in comparison with an average paved route, if the geometry characteristics remain constant. Further comments are made later in this paper about roughness effects and their influence on depreciation and interest.

It can also be seen from the results that all of the derived equations are weak for the geometry measures. Not only are the coefficients small but also they are not significant at the 90 percent level. This is contrary to expectations and apparently in conflict with the mass of experimental data on vehicle speed, which clearly demonstrates that vehicle speed is strongly influenced by vertical geometry. Vehicle speed is related to use through hours driven, and thus vertical geometry would be expected to be a main effect in any prediction of use from highway characteristics.

The answer may come from further analyses. A larger data set is being assembled, and further analyses will be conducted when it is complete. It should be stated, however, that many different forms of analysis have already been tried and that none have produced large, well-determined coefficients for the geometry measures.

A potential reason for this phenomenon lies in economic theory. The companies that furnished data can be regarded as rational profit seekers. They must cover all costs and achieve some rate of return to remain in business. The fact that speed is influenced by vertical geometry is a physical relation, not an economic one. Vehicle use, however, is an economic response (rates exceeding all costs), not a physical one. So there, perhaps, we have it. We know that surface condition affects practically all user-cost items (9), whereas vertical geometry affects essentially only fuel and time-related costs. Therefore, a very rough route results in very high user costs, very high rates charged, and a reduced demand for transportation. A very hilly route does not result in such higher costs, the rates charged are not so high, and more demand (use) results. A further point is that a user route, as opposed to a particular road section, has compensating features. Even in very hilly terrain, vehicles go down as well as up, thus reducing the effect of vertical geometry on average vehicle trip speed.

It may be, therefore, that vertical geometry has a very small effect on vehicle use (and thus time-related costs such as depreciation and interest), and this itself could be even more important than the relation between vehicle use and roughness.

So it is possible to defend a small vertical-geometry effect, but why is it not well determined? This may be due to an overestimation of the model's pure residual error in hypothesis testing. The data set is not an experimental one and therefore not truly randomly derived, so it is possible that the residual error has two components: (a) a constant (or constants) attributable to fixed but unmeasured effects and (b) the true pure-error term. The constants may, for example, be present because of company policies. Such constants are present in many large surveys. [Income studies are good examples of this: Constants for rich and poor members of the community make hypothesis testing questionable, low R^2 values abound (often less than 0.20), yet predictions remain surprisingly good.] They will recur in any new population and will not affect the accuracy of the prediction. Therefore, if they can be removed from the residual error of the model, hypothesis testing can be done by using the valid pure-error term. Since this component must by definition be smaller than the residual error currently used, geometry might become more significant. In these circumstances, it seems preferable to report the geometry effect in the equations so that a user can make up his or her mind as to their inclusion in any prediction. It is thought that geometry should have some effect on levels of vehicle use, although perhaps a much smaller effect than previously believed, and there are not yet sufficient grounds for fully rejecting the coefficients reported in the equations. Future work will include an attempt to estimate this fixed component, which is believed to be part of the current model's residual error. Mention was made earlier that it might be preferable to use individual vehicles, rather than company-cell means, in regression analyses. Aggregation is to be regarded with suspicion because one risks losing statistical efficiency and masking (perhaps deliberately) certain effects. A series of regressions were therefore run in which only individual-vehicle values were used. The results were interesting because they confirmed the earlier analysis of variance results of the between-company and within-company effects. The equation coefficients are very similar to those reported in this paper. There is clearly nothing to be gained from pursuing this approach in preference to company-cell means. The latter approach does not mask any important effects that are revealed by analyzing individual vehicles and indicates more about the statistical influences at work in the data set.

Since it was known from the work of Moyer and Winfrey (1) that vehicle age could have a significant effect, the analyses performed included the influence of age. Some of the results are given below (from the RFP formula in Table 1):

Age of Vehicle (years)	Use (percentage of use of vehicle when new)
1	94
2	89
3	84
4	79
5	74
6	70
7	66
8	62
9	58
10	55

The table indicates that a 10-year-old Brazilian truck exhibits a 55 percent reduction in use from the level of use when it was new. Vehicle use with respect to age tends to be "stepped" in actual vehicle operation, as shown by Edwards and Bayliss (10), and this is confirmed in Brazil. The preliminary analyses on the age effect have smoothed out this feature to give an annual change of use of approximately 6 percent. The purpose of this paper, however, was to determine the relation between vehicle use and highway characteristics, so age is not a central theme. Nevertheless, it is gratifying to see that the age effect confirms prior reasoning and that its coefficient was significant. Clearly, more work is warranted in this important area of vehicle characteristics and use.

VERIFICATION OF RESULTS

An effective way of verifying the robustness and strength of a model is to test it by using data that are not used to derive the regression coefficients. The equation can be tested by comparing the original coefficients with coefficients estimated from the supplementary data set.

This has been done for the RPF formula in Table 1 by using 145 of the 200 vehicles excluded from the original data set because of lack of route characteristics, which were subsequently obtained. These 145 vehicles resulted in 39 means derived from highway-characteristic and company cells (Figure 4), distributed as follows:

1. Commercial automobile—7 means;
2. Utility vehicle—3 means;
3. Bus—23 means; and
4. Medium truck—6 means.

No heavy trucks were available.

An F-test was performed to test the hypothesis that

$$H_0 : b_{new} = b_{old} \tag{4}$$

where b_{new} and b_{old} are the vectors of coefficients of the regressions on the new data set and the original one, respectively. The appropriate F-value is

$$F_{P, J-P} = [(b_{new} - b_{old})^T X^T W X (b_{new} - b_{old})/P] \div [SSE_{new}/(J - P)] \tag{5}$$

where

P = number of coefficient estimates = 7,
J = number of means in the new data set = 39,
X = matrix of independent variables in the new data set,
X^T = transpose of X,
W = matrix of weights from the new data set, and
SSE_{new} = error sum of squares for the regression on the new data set.

The calculated $F_{7,32}$ value was 0.58, which is less than the tabled value at $\alpha = 0.25$, so we accept the hypothesis that the coefficient estimates from the supplementary data set are not significantly different from the original values and thus verify the applicability of the latter to the new data.

SUMMARY OF RESULTS

The preliminary results of work currently being carried out in Brazil on vehicle use are extremely interesting to the transportation economist and the highway planner. Previously, estimates of vehicle use were most popularly derived from the product of speed predictions and hours driven, the latter both being sensitive and lacking any empirical base for estimation. The approach reported in this paper attempts to predict vehicle use directly from highway characteristics and is both simpler and potentially more accurate than previous approaches. Difficult issues, such as hours driven, are subsumed within usage data taken directly from operators' records. These individuals, who are rational decision makers in the sense of wishing to remain in business, can be regarded as being in long-term cost equilibrium with their highway characteristics. Vehicle use is an economic response, and direct observation—through collection of cost records on operators' economic behavior (vehicle use) with respect to highway characteristics—clearly has merit.

Preliminary equations reported in this paper show promise. A clear relation between vehicle use and roughness (surface condition) is demonstrated and, more controversially, a small vertical-geometry effect is reported. These equations have considerable importance in the widely used procedure for calculating depreciation and interest, a method that regards vehicle value and its change over time as a constant with respect to highway characteristics. Differential rates for depreciation, and hence interest, per kilometer are then determined by the different levels of use with respect to highway characteristics:

Measure	Paved Road	Unpaved Road
Roughness (QI*/km)	43	145
Vertical geometry (RPF)	30	30
Life (years)	10	10
Depreciable value ($)	20 000	20 000
Lifetime use (km)	976 850	676 630
Depreciation cost ($/1000 km)	20.47	29.56

In the table above, it can be seen that the depreciable value of the vehicle is constant at $20 000, irrespective of the road type. The information is based on a truck with a gross vehicle weight of 15 t that operates all its life on routes characterized by the mean roughness values of the paved and unpaved roads in the Brazil study. A differential rate of 1.44 between unpaved and paved is predicted; this makes it possible to calculate a differential rate of depreciation per kilometer. Interest is not included, but it would be similarly influenced by use.

In addition, it is useful to make some comparisons with previous studies. Unfortunately, this has to be tentative since no other work has attempted to quantify vehicle use from highway characteristics. Nevertheless, it seems worthwhile to try and make some comparisons. The following table compares the percentage decreases in use of a medium truck on various road surfaces:

Source	Differential Rate of Decrease in Use: Paved Versus Improved Gravel	Paved Versus Unimproved Gravel
Brazil	0.91	0.77
Bonney and Stevens (2)	0.86	0.68
Hide and others (3)	0.87	0.71
HDM (6)	0.95	0.87

The following assumptions are made:

1. For the Brazil survey data, RPF = 30 m/km, roughness for paved road = 40 QI*, roughness for improved gravel = 80 QI*, roughness for unimproved gravel = 150 QI*, and average medium-truck age = 4.3 years.
2. For the Hide and others (TRRL) data on Kenya (3), differentials are based on speed changes (assuming constant hours driven). Rise and fall = 15 m/km each, horizontal curvature = 60°/km, altitude = 1300 m, and roughness for paved road = 2500 mm/km. For improved and unimproved gravel, roughness = 6000 and 10 000 mm/km, rut depth = 19 and 40 mm, and moisture content = 2.6 and 10 percent, respectively.
3. For the HDM adjusted utilization method (6), truck speeds (determined from experimental speed data from Brazil) were 60 km/h for paved road, 47 km/h for improved gravel, and 34 km/h for unimproved gravel.

These calculations are made for a medium truck, although the definition for this vehicle varies between studies. The HDM is not a data source but rather a synthesis of previous research and is included in the comparison because it is being widely adopted as a planning guide. The procedure reported is only one of its options for the calculation of vehicle use. Its higher predicted values, particularly with respect to unimproved gravel, indicate that hours driven is a critical assumption in the option and is possibly overestimated.

It is gratifying to note that the Brazilian predictions are not broadly inconsistent with previous research studies. This suggests that this simpler method has much to recommend it, and work is continuing on further analyses. The approach should enable economists and highway engineers to estimate vehicle use in Brazil, and possibly other countries, without having to rely partly on assumptions that are difficult to substantiate.

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