EVALUATION OF ALTERNATIVE TRANSPORTATION INVESTMENT DECISIONS: MODIFICATION AND USE OF A MULTIREGIONAL INPUT-OUTPUT MODEL

Martin M. Stein, Office of Program and Policy Planning,
Federal Highway Administration; and
Ernest J. Mosbaek, Jack Faucett Associates, Inc., Silver Spring, Maryland

The researchers describe an additional technique for evaluation of alternative transportation investment strategies. This technique involves the modification of a gravity parameter multiregional input-output model. In a gravity parameter model, the volume of shipments between two regions is specified as a function of demand in the importing region, production in the exporting region, and total production in all regions. The gravity model becomes useful for analysis of transportation investment when it is modified to allow prediction of regional economic effects from investment. This research project focused on a case study in highway investment—the National System of Interstate and Defense Highways. Availability of a special tabulation of the 1963 Commodity Transportation Survey permitted regression analysis of the relationship between quality of highways and value of trade parameters in the gravity model. The authors present the formulation of an augmented gravity parameter model based on the regression analysis. The augmented model offers potential for estimating shifts in economic activity among regions and increases in the demand for transportation. Preliminary results show that a simpler version of the multiregional input-output model—one based on constant regional imports—is a good substitute for the more complex gravity trade version.

• SEVERAL FEDERAL AGENCIES are cooperating in the development of a multiregional input-output model (13). The data that have been assembled in this effort and the model itself provide new opportunities for better evaluation of transportation investment. In particular, the differential economic effects among regions can be estimated.

It has been suggested that the early approaches to transportation planning such as the "bottleneck approach" or individual project analysis are not suitable for evaluating total transportation system requirements or benefits (17, 18). In fact, the most recent trend appears to be toward the use of a combination of models that consider more than one transportation mode. As shown in Figure 1, analysis may include several models, each providing an important perspective to the decision-maker. This paper focuses on a new opportunity for use of the "economic model."

There is growing recognition that transportation planning requires detailed estimates of economic effects from investment expenditure. This has sparked increased interest in the application of partial or general equilibrium economic models. These models seek to include most relevant economic variables within the same analytical framework. This is particularly significant because it highlights the multiple objectives of transpor-

Sponsored by Committee on Transportation Programming, Planning and Evaluation and presented at the 50th Annual Meeting.

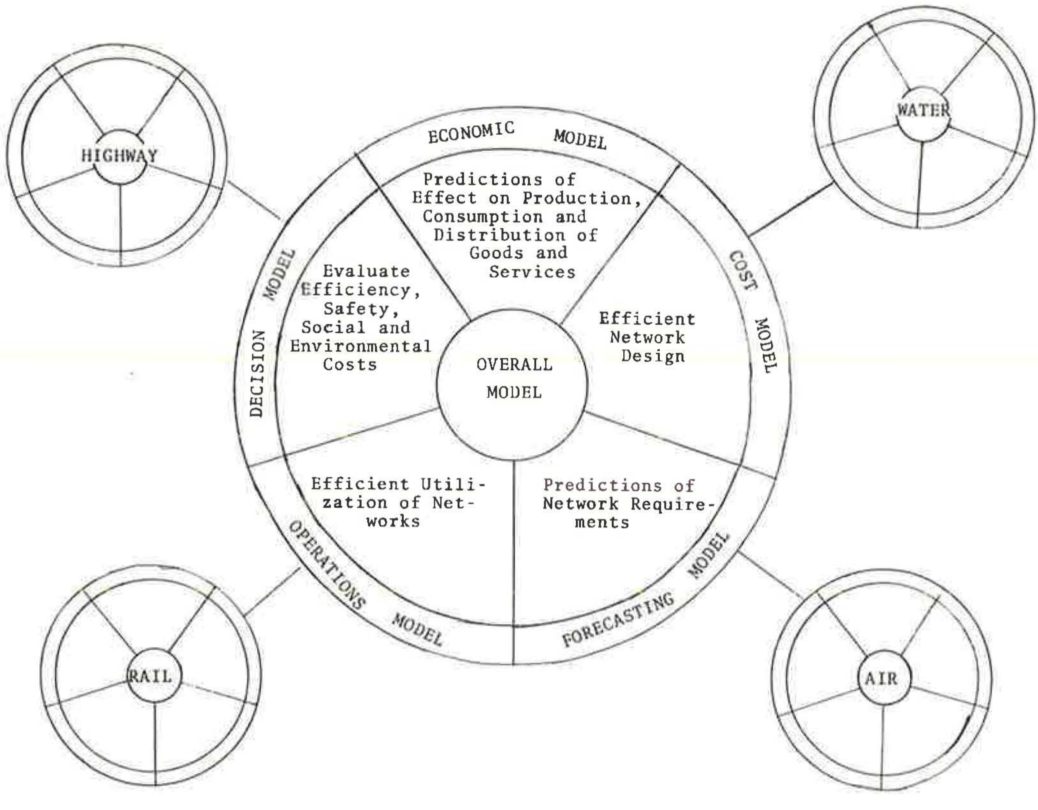

Figure 1. Analysis of public investment in transportation.

tation investment and the numerous social and environmental factors that must be considered. Some questions frequently asked include the following:

1. Should new transportation systems be constructed to minimize transportation costs, or should regional and urban development be a factor in system selection?
2. Will the system result in changes in relative accessibility that in turn influences industrial productivity and regional comparative advantage?
3. Will these changes result in employment and population shifts that also affect the demand for transportation?

The development of an integrated model, or a combination of models, has been limited to a large extent by the lack of a body of compatible data. Model builders usually have to develop large portions of data and often have to adapt existing data that are not compatible with the model. A significant portion of our research effort was devoted to a special tabulation of the Commodity Transportation Survey of the 1963 Census of Transportation. In addition, another effort was required to develop a series of transportation network flow data to make the multiregional model itself operational (6).

The availability of a multiregional input-output model expands the horizons of transportation planners by providing the potential for examining economic effects of proposed changes in the transportation system. For example, changes in highway capacity produce changes in regional output that, in turn, affect the demand for highway transportation (Fig. 2).

Phases 1 and 2 of the overall research project design, shown in Figure 2, are now complete. Results indicate that an approach using a multiregional input-output model will improve the capability for evaluating alternative investment decisions. However,

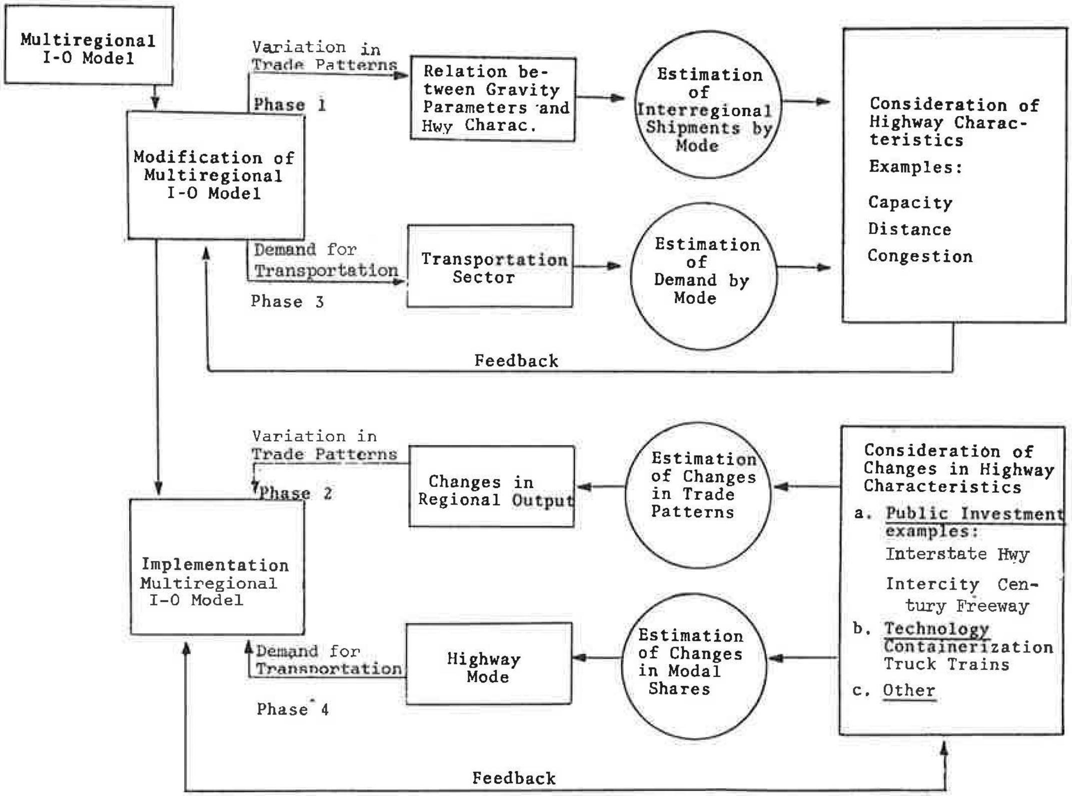

Figure 2. Modification and implementation of a multiregional input-output model (estimation of regional economic effects of highway investment).

other research on the effects of technological changes on transportation requirements will provide much greater insight into the usefulness of this approach (7).

MULTIREGIONAL INPUT-OUTPUT MODEL

The Harvard Economic Research Project is developing a gravity parameter multiregional input-output model based on 1963 data. The model, which is scheduled for completion this year, describes economic activity for 82 economic sectors for 40 individual states or combinations of states (15). The Harvard model is based on the Leontief-Strout formulation of the multiregional input-output model and expresses interregional trade in the form of gravity parameters (9). The gravity parameters relate freight shipments by all transportation modes to production and consumption for each input-output sector by the formulation

$$\text{Shipments} = \frac{(\text{gravity parameter})\ (\text{demand } R_i)\ (\text{sales } R_j)}{\text{national sales}} \tag{1}$$

where demand R_i is the total of intermediate and final demand in region i, the receiving region; sales R_j is the total production in region j, the shipping region.

Developing a separate gravity parameter for the highway mode and expressing it in terms of highway characteristics permit the estimation of regional economic effects of highway investment (5). The functional relationship between the gravity parameter for a commodity and highway characteristics can be established by statistical analysis of variation in interregional trade and variation in quality of highways.

Data requirements for development of the multiregional model and development of equations to predict changes in gravity parameters are extensive. Data on state-to-state shipments of commodities by transportation mode for at least one base period are essential. Although this type of information is available for specific commodities such as fruits and vegetables (12), only two sources are available for a broad range of commodities. One source is the published data from the 1963 Census of Transportation, and the other is a special tabulation discussed in the next section.

The Harvard model and the data bank developed in the process of building the model provide a valuable resource for many types of regional analyses. The investment in the Harvard project would be prohibitive for many prospective users. Our research has taken advantage of the Harvard results; it has centered on two aspects that are discussed later in greater detail. One aspect is development of the theory and concepts for using a multiregional model to estimate economic effects from highway investment. A second aspect is development of a means to estimate the changes in trade parameters brought about by improvements in highways from investment programs such as the Interstate System.

The Harvard model is easily adapted to estimate short-term effects of highway expenditures on the construction and related industries. This paper is mostly concerned with the indirect, and possibly the more significant, effects stemming from changes in trade relationships between regions. A procedure for modifying the multiregional model for use in estimating these types of effects is presented in a following section.

SPECIAL TABULATION OF THE COMMODITY TRANSPORTATION SURVEY, CENSUS OF TRANSPORTATION

Until 1963, the 1 percent survey of railway bills by the Interstate Commerce Commission provided the only extensive information on the origin and destination of goods by public carriers. In 1963, the first U.S. Census of Transportation included a survey of nearly 10,000 manufacturing establishments. The shipments from these establishments were classified into 25 shipper groups, 86 shipper classes or subgroups, and 175 types of goods (16). The published results of this survey presented flows to and from 25 multicounty "production areas" and 9 census regions. A special tabulation of this data was prepared for the Federal Highway Administration so that state-to-state flows by mode could be identified. Although some of the information will be lost as a result of the disclosure regulations, this new tabulation provides greater geographical and commodity detail than previously available data.

This special tabulation has provided the information needed to develop the Harvard model at the state level and to develop the equations for relating changes in trade coefficients to improvements in highways. These data can also be useful in identifying the major imports and exports of each state and their predominant mode of transportation. The availability of both a model at the state level and equations to predict changes in trade coefficients is especially important because of the increase in economic planning at the state level.

The tabulation specifies volume of shipments for each of 54 input-output sectors. The conversion from the Transportation Commodity Code (TCC) to input-output sectors is carried out using the TCC/SIC Product Code Bridge, 1967, and information on the SIC classification of each reporting establishment. The principal measurements are tons and ton-miles shipped between cities, classified by mode of transport, commodity, size of shipment (weight basis), distance, origin, and destination (2). Other information on characteristics of shippers includes industrial classification, size class (based on number of employees), geographic location, and general types of transport facilities available to the plant. The 1963 survey consisted of 8,752 manufacturing establishments in the "major industrial sector" (plants with more than 20 employees) and about 1,400 plants in the "small industrial sector" (plants with less than 20 employees). Sample plants in the first group accounted for 96 percent of total tonnage originated by all manufacturing plants but represented only 32 percent of the total number of establishments; sample units in the second category accounted for less than 4 percent of total tonnage and represented 18 percent of the total number of establishments.

Although this survey is limited to products of manufacturing establishments, these products probably represent 75 to 80 percent of the dollar value of total commodity movements and 50 percent of highway commodity movements. In addition, other surveys now being contemplated, such as a truck use study and truck weighing station data, will help provide data on nonmanufactured commodities and will account for most freight shipments in the economy by these industries in each state.

Although there are still some fairly severe data limitations, the special tabulation discussed in the preceding has provided the basic information for developing and augmenting the Harvard model so it can be used to evaluate alternative transportation investment programs.

DEVELOPING EQUATIONS FOR PREDICTING CHANGES IN TRADE PARAMETERS

The multiregional input-output model specifies the relationship between volume of trade between regions and volume of production and consumption in these regions. These relationships are expressed in terms of trade parameters.

Both the trade parameters and interindustry coefficients in an input-output model are estimated from data for a base period. In most applications of an input-output model, it is assumed that all parameters of the model remain constant, and, therefore, the model can be applied in a straightforward manner. In analysis of highway investment, this assumption is obviously unrealistic.

One of the objectives of highway investment is to reduce the cost of transportation and facilitate interregional trade. Therefore, we expect investment to cause changes in trade parameters. To use an input-output model developed from data for a base period prior to the highway investment, one must develop equations for estimating the effect of the highway investment on trade parameters. That is, it is necessary to supplement the input-output model with auxiliary equations that specify how the trade parameters estimated from the base period data will change.

The best possibility for developing these auxiliary equations is multivariate analysis of cross-sectional or time-series data. The most complete and readily available data on trade between regions within the United States is the 1963 Census of Transportation (16) because only limited portions of the 1967 census were available in 1970. This provides several opportunities for cross-sectional analysis of the relationship between volume of highway freight and quality of highways.

It is necessary to use multivariate analysis because distance between two regions as well as quality of transportation is important in determining volume of trade. The basic equation used to explain variation in trade parameters between two regions is

$$\text{Trade parameter} = a_0 + a_1D + a_2C \qquad (2)$$

where D is distance between the origin and destination regions and C is cost of transportation per unit of distance. In application of the multiregional model, the value for each trade parameter is determined by the equation

$$\text{New trade parameter} = \text{old trade parameter} + a_2(C^* - C) \qquad (3)$$

where $C^* - C$ is the reduction in cost of transportation as a result of a transportation investment program, and a_2 is obtained from regression estimates of Eq. 2. In our research to date, which primarily involves highway investment, the variable C has been measured in terms of average miles per hour for trucks.

Equation 2 is fitted for each input-output sector in the multiregional model. The result for the metal-working machinery sector shown in Eq. 4 is fairly typical of the results obtained to date.

$$\text{Trade parameter} = 0.19 - \underset{(0.00006)}{0.0016(D)} + \underset{(0.0056)}{0.0044} \quad R^2 = 0.38 \qquad (4)$$

Equation 4 was estimated by using data from the special tabulation of the 1963 Census described in the previous section.

Further research on the effect of highway investment on volume of trade between regions should center on (a) determining the reduction in cost of transportation, variable C in the preceding equations, for given types of highway investment, and (b) improving the statistical estimate of the coefficient a_2 in Eq. 2. In our research to date the estimates of a_1 and a_2 are unrealistic in the case of some input-output sectors.

Several different mathematical expressions have been tried in Eq. 2, but none is significantly better than the linear form. It appears that either the data from the 1963 census are not adequate for estimating the coefficients, or there are important explanatory variables left out of Eq. 2. More research is needed on this important topic.

APPLICATION OF A MODIFIED MULTIREGIONAL INPUT-OUTPUT MODEL

A considerable portion of the research in evaluating alternative highway transportation investment decisions has been limited to small geographical areas such as cities or corridors along a particular road. However, the utilization of a multiregional input-output model will permit analysis of the broad economic impact of total highway networks such as the Interstate System. Predicted changes in gravity parameters can be inserted into a multiregional model developed from data for a base period, and the model can be used to simulate the effects of proposed highway investment on national and regional development.

Estimates of the economic effects of the Interstate System on census regions provide one illustration of potential applications of this technique in evaluation of an actual transportation investment. Preliminary analysis indicates that the impact of an investment of this magnitude has a significant effect on both the total transportation system and the economy of some regions.

The use of an augmented multiregional model is given in Table 1. For any specified region the economic effects are measured by comparing the simulation in the upper left with that in the lower right of the table. In some cases, actual observation of economic activity can be used instead of simulation of one or the other of the two situations. The essence of our proposed technique is to compare regional economic activity with and without a specified highway investment program. Table 1 highlights the facts that the two major causes of differences between these situations are change in trade patterns and change in demand for regional products.

There are three types of multiregional models that can be developed from available data: gravity parameter, constant regional imports, and constant regional exports. The first type was described previously. The second is based on the assumption that imports into a region are a fixed portion of total demand in the region, while the third is based on the assumption that exports to each of the other regions is a fixed portion of the production in the exporting region. The application of each type of multiregional model is essentially the same and will not be discussed in this section. However, the quality of results from application can differ depending on the realism of the underlying assumptions. Some preliminary research on this has been done and is reported in the next section.

TABLE 1

COMPARISON OF ECONOMIC ACTIVITY WITH AND WITHOUT SPECIFIED HIGHWAY INVESTMENT

Interregional Trade	Demand for Regional Products	
	Without Highway Investment Expenditures	With Highway Investment Expenditures
Without improvement in highway	Activity without investment	
With improvements from highway investment		Activity with investment

There are undoubtedly several ways of augmenting the multiregional model to improve its usefulness for transportation policy questions at the federal and local levels of government. Our research has focused on one major augmentation—equations for predicting changes in trade parameters—and was oriented toward policy questions on major federal programs such as the Interstate System.

In a recent U.S. Department of Transportation seminar on input-output analysis and transportation planning, several applications of input-output analysis were discussed (17, 18). The applications focused on (a) determining freight requirements, (b) estimating effects of highway investment on differential rates of economic growth among regions, (c) identifying employment-creating effects of highway investment, (d) estimating the long-run effects of improved transportation on shifts in population among regions, and (e) choice of highway investments with respect to interindustry effects.

Simulations using a multiregional input-output model can provide a basis for estimating transportation requirements. The estimates of interregional trade from simulations can be converted to trips or ton-miles. By modifying the input-output model along the lines proposed in this paper, simulations provide estimates of regional economic activity. The Bureau of Labor Statistics is currently developing employment projections based on input-output relationships (8), providing a means for converting estimates of production by region into employment. With further development work, the multiregional model can provide inputs for estimating population shifts and interindustry relationships.

Another technique for augmenting input-output analysis is offered by Mohring and Williamson who use gasoline consumption estimates to determine the value of transportation services provided by private trucking for 192 industrial sectors of the 1947 input-output tables (11). Similar estimating techniques will be helpful for increasing the value of input-output models to transportation planners.

CONCLUSIONS

The multiregional input-output model augmented with equations for predicting changes in trade patterns is a valuable addition to the existing techniques for evaluating highway investment. It allows the analyst to provide decision-makers with better information on the effects of alternative transportation investment strategies.

Highway investment has generally been considered to have a positive effect on the economic development of states and regions. The magnitude of effects is difficult to estimate because highway investment generates additional expenditures by several types of indirect effects. The location of benefits is difficult to identify because (a) the trade patterns among states cause some of the benefits from federal expenditures in a specified state to be distributed to other states; and (b) improved highways lower the cost of transportation, creating shifts in location of production among states. Federal and state officials are interested in knowing the magnitude and location of benefits so they can better appreciate the full impact of highway expenditures.

The capability of input-output models for estimating effects from highway investment is given in Table 2. The simple ratios designated in the first column are developed from data on the construction industry. For example, the employment ratio for the construction industry is estimated by multiplying highway construction expenditures by the employment-sales ratio.

It should be pointed out that reductions in costs of transportation are not easily estimated by using input-output analysis. Multiregional input-output models can be used to estimate volume of trade, but the savings in cost per unit shipped must be built up from engineering data. It is useful to classify impact of highway investment in terms of (a) savings in transportation costs and (b) stimulation of or shifts in economic activity. It is not possible to say that one is more important than the other: both must be considered in a proper evaluation of highway investment. The augmented multiregional input-output model described in this paper takes us a long way in obtaining good estimates of the second item.

There are numerous studies that provide estimates of economic impact of highway investment on a specific city or impact of, say, a highway interchange on the immediate

TABLE 2

USE OF INPUT-OUTPUT MODELS IN ESTIMATING EFFECTS OF HIGHWAY INVESTMENT

Effects	Simple Ratios	Regional Input-Output Model	Multiregional Input-Output Model	Multiregional Model With Equations for Predicting Trade Patterns
Direct effects from expenditures	Yes	Yes	Yes	Yes
Sum of direct and indirect effects from expenditures		Yes	Yes	Yes
Location of direct and indirect effects from expenditures			Yes	Yes
Total effects, including shifts in production				Yes
Feedback between transportation capacity and demand for transportation				Requires further development

vicinity. A variety of techniques have been used. The input-output technique proposed in this paper has two major advantages over the methods commonly used in these studies. First, it can be used to estimate net effects in a state or multicounty area; the other methods do not provide a means to determine if the increased economic activity near the improved highway stems from a decrease in another part of the county or state. Second, an input-output model can be used to estimate the effects of hypothetical investments. Many of the methods used in estimating effects that are immediately adjacent to a highway either involve a great amount of detailed investigation or rely on an assumption that the effects will be similar to those observed in a previous situation. Both constraints severely limit the usefulness of these methods for analyzing numerous hypothetical investments or investments as complex as the Interstate System.

Models are necessary for understanding the many complex relationships that determine need for and impact of highway investment. It is important to realize that it is the inherent nature of the subject area that makes analysis difficult, not the complexity of the input-output model or other form of model that is used in analysis.

The use of input-output models makes it possible to consider economic effects of highway transport in conjunction with that of other modes (Fig. 1). An adequately defined model structure permits analysis of the combined effects from investment in all modes on regional economic activity.

REFERENCES

1. Burns, R. E. Transport Planning: Selection of Alternative Techniques. Jour. of Transport Economics and Policy, Vol. 3, No. 3, Sept. 1969.
2. Church, D. E. Sample Design: Commodity Transportation Survey, 1967 Census of Transportation. U. S. Bureau of the Census, 1968.
3. Gamble, H. B., et al. The Impact of Interchange Development on the Economy of Clinton County. Institute for Research on Land and Water Resources, Pennsylvania State Univ., University Park, 1966.
4. Economic Dependency on Highways. Jack Faucett Associates, Inc., Silver Spring, Md., 1970.
5. Highway Investment and Regional Economic Effects. Jack Faucett Associates, Inc., Silver Spring, Md., June 1970.
6. 1963 Interregional Commodity Trade Flows. Jack Faucett Associates, Inc., Silver Spring, Md., 1970.

7. Evaluation of Potential Effects of Intermodal Freight Transportation Advances on Highway Requirements: Study Design Phase. A. T. Kearney and Company, Chicago, 1969.
8. Kutscher, R. E. 1980 Projections in an Input-Output Framework. Presented at the Internat. Marketing Congress of the Marketing Assn., Philadelphia, 1968.
9. Leontief, W. Input-Output Economics. Oxford Univ. Press, New York, 1966.
10. Madsen, K. L. An Estimated 1967 Input-Output Model for Southwestern Wyoming. Wyoming Division of Business and Economic Research, Laramie, 1968.
11. Mohring, H., and Williamson, H. F., Jr. Scale and "Industrial Reorganization" Economics of Transport Improvements. Jour. Transport Economics and Policy, Vol. 3, No. 3, Sept. 1969.
12. Polenske, K. R. A Case Study of Transportation Models Used in Multiregional Analysis. Harvard Univ., Cambridge, Mass., PhD dissertation, 1966.
13. Polenske, K. R. A Multiregional Input-Output Model for the United States. Harvard Economic Research Project, Harvard Univ., Cambridge, Mass., Oct. 1970.
14. Polenske, K. R. An Empirical Test of Interregional Input-Output Models: Estimation of 1963 Japanese Projection. Harvard Economic Research Project, Harvard Univ., Cambridge, Mass., 1969.
15. Polenske, K. R. Interim Report on the Multiregional Input-Output Research Program. Harvard Economic Research Project, Harvard Univ., Cambridge, Mass., Rept. 6, 1968.
16. Commodity Transportation Survey, 1963 Census of Transportation, Vol. 2. U.S. Bureau of the Census, 1967.
17. Input-Output Analysis and Transportation Planning. Office of Economics and Systems Analysis, U.S. Department of Transportation, Jan. 1969.
18. Goldstein, S. Input-Output Analysis and Highway Transportation. In Input-Output Analysis and Transportation Planning, Office of Economics and Systems Analysis, U.S. Department of Transportation, Jan. 1969.
19. Transportation Information. A report to the Committee on Appropriations, U.S. House of Representatives, from the Secretary of Transportation, 1969.