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Multi-Mode Intercity Freight Transportation Planning for Underdeveloped Regions†

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MUCH OF TODAY'S intercity freight and passenger transportation planning is based on the same deficiency approach that is used to identify urban transportation needs. This approach is supported by recent work by and for the U. S. Department of Transportation. A set of passenger and commodity flow data and projections has been prepared and is partially documented (4). Network models (1,3) and model split equations (2) are also available. This approach is appropriate for highly developed regions where traffic congestion is a problem and where the pattern of future growth can be easily discerned.

In underdeveloped regions, the planning problem is very different. Present traffic levels are low because economic activity is limited and highways, railroads, and waterways are often of secondary quality. In these regions, the patterns of economic activity cannot be predicted from past trends because past trends lead nowhere. If the region is to grow economically, new breakthroughs are needed. New industry must be established in locations that were not heretofore possible. Future growth depends on the ability to identify, locate, and exploit these new opportunities.

A trigger of some sort is needed to initiate sound development. This trigger might take many forms: discovery of a new mineral deposit, availability of a new energy resource, development of a new market, or the construction of a new or improved transportation facility. The last trigger, transportation, has been effective in many ways for many years. New transportation services have played a key role in the development of this country. Most recently, the Interstate and Defense Highway System has triggered new growth in newly served regions.

Several efforts have been made to related economic growth to transportation improvement. Harris (5) has developed an input-output based model that relates growth to highway improvements. He considers a variety of economic factors together with a set of marginal transportation costs that describe the effects of highway improvements. He treats transportation costs in terms of origin-destination pairs and hence treats intermediate improvements in terms of apparent shortest routes. He does not treat intermodal shipments. Coyle et al (6) developed an input-output based model that considers multi-mode transportation. However, this model does not consider intermodal transfers as part of a shortest route. The different modes are kept separate. Wendt (7) has developed an input-output based model that uses accessibility and attractiveness indices to relate land use to the quality of transportation. This model also bases its analysis on the preselection of routes between origins and destinations so that transportation cost and time can be inputs to the development decision. Each of these models is too deeply imbedded in conventional assumptions to effectively evaluate either extensive intermodal transportation development or radically new transportation services.

MULTI-STATE TRANSPORTATION SYSTEM

Although the techniques presented in this paper are believed to be generally applicable to underdeveloped regions, they have been designed for application to a particular multi-state corridor. The multi-state corridor of interest includes parts of eight states and extends from Brunswick on the Georgia coast to Kansas City. The study area is approximately 1200 miles long and 100 miles wide.

Interest in this region has been stimulated by the Multi-State Transportation System Advisory Board, a group of public and private officials that was formed in 1972. It is the objective of this Board to stimulate the economic development of the Multi-State corridor through improved inter modal transportation. The Multi-State Board has been very active in generating support for corridor development. Several studies (8,9,10) have been performed; others are underway. All point to the need for the research described here.

MULTI-STATE AREA

The Multi-State study corridor contains four large urban areas—Jacksonville, Birmingham, Memphis, and Kansas

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City—but it is otherwise underdeveloped. The population is poor—with perhaps the lowest average income of any comparable group in the United States. The principle rural economic activity is marginal farming. Several Interstate Highways cross the area but none travels its length, nor is there a south-east to north-west Interstate Highway anywhere in the Southeastern United States. The Multi-State corridor is served by a main line of the Frisco Railroad between Kansas City and Birmingham, but otherwise it is served by only secondary rail lines. The corridor is crossed by a number of major waterways including the Mississippi, Tennessee, Alabama, and Apalachicola/Chattahoochee rivers and the Tennessee-Tombigbee waterway. Transportation opportunities abound but they are not put together into a network that can serve the Multi-State corridor. Service to the corridor is, in most instances, incidental to other areas. Existing facilities have been primarily designed to cross the corridor as a means to serving other areas. The challenge of Multi-State development is to identify and build the new transportation links that are needed to make the existing facilities more productive to the economic growth of the area. The transportation facilities of interest will not constitute a massive public works program. Rather, facilities will be tailored to economic opportunities as they are identified. Existing and planned facilities will be incorporated into the systems with such modifications as are needed. Facility ownership will be public but users—carriers, shippers, and others—will be private. Users will pay for the use of the new facilities through existing or new fee structures.

The new facilities will be designed to serve both new and existing industry. Some traffic will both originate and terminate inside the study corridor. However, the vast majority of traffic will originate or terminate outside the corridor or both. To the extent that new highway and rail facilities tie into existing networks, traffic can take advantage of new high quality links for a variety of trips. Modal interchange terminals will be also considered so as to make maximum economic use of intermodal combinations.

THE ANALYTICAL PROBLEM

The analytical problem is to jointly identify development opportunities and the transportation facilities needed to assure their economic viability. The analysis is of necessity money based. To be successful, a new facility must be able to produce and deliver its products to a sufficient number of markets at a cost that is comparable to the costs of other facilities with which it must compete. The costs of delivering competitive products to a market place include the costs of (1) raw materials, (2) direct labor, (3) indirect labor, (4) energy, (5) capital, (6) taxes, and (7) transportation, as well as others. Six of the seven cost categories enumerated above exhibit geographical differences. The seventh. capital cost, is a measure of the mobility of an industry. The measure of economic viability for a new industrial facility is whether it can compete in a sufficient number of markets to support a financially viable facility size.

The objective function used in the analysis combines amount of labor employed in the corridor, the gross product or corridor industry and transportation cost savings in the U. S. markets as a whole. Attractive development programs will show high values for the objective function. The research will not lead to an optimal value.

When testing new facility types and locations, the raw material costs, labor rates. energy costs, and taxes are characteristics of the selected locations. Transportation costs depend on the sources of raw materials, on the locations of the markets to be served, and the amount and quantity of the services available between the new facility and its potential markets. Transportation cost and service are subject to change by the construction and operations of new transportation services or by the facilitation of advantageous intermodal transfers.

THE ANALYTICAL FRAMEWORK

The analytical framework selected for study is somewhat simpler than those selected by Harris (5), Coyle (6), and Wendt (7). In particular, the input-output analysis has been ommitted. By omitting the input-output analysis. a complex analytical structure with many uncertain coefficients has been avoided. The price for this simplification has been the tacit acceptance of an important assumption. For purposes of analysis, the total volume of goods moving in commerce is assumed to remain unchanged throughout the U. S. The relative contributions of competing services will change. This assumption is necessary because there is, at present, no mechanism for estimating or evaluating the impacts of shifts in industrial location short of input-output analysis. This assumption is acceptable as long as the objective of the research is to identify development opportunities within the present industrial environment. When one seeks to measure the full impact of these developments, it will be necessary to take shifts into account. However, that more detailed analysis can focus on more specific industrial sectors than is now possible.

The analytical framework is expressed in terms of commodity flow between pairs of network zones. Commodities, in turn, are amalgamations of more or less homogeneous groups of industries that produce the different commodity groups. Each group is identified in terms of the Standard Industrial Classification (SIC) Codes.[1] Each industry/commodity group is described by an industry profile that identifies the key cost components for a typical facility. Network zones are connected by arcs that represent the different transportation facilities that are available. Separate arcs have been prepared for highway, rail, and water modes. Additional arcs can be added for postulated new facilities. Nodal impedances reflect transfer time and cost.

Figure 1 illustrates the analytical procedure which is divided into two parts. The first part establishes the analytical framework and prepares the necessary data. The second part is an iterative

ANALYTICAL PROCEDURE

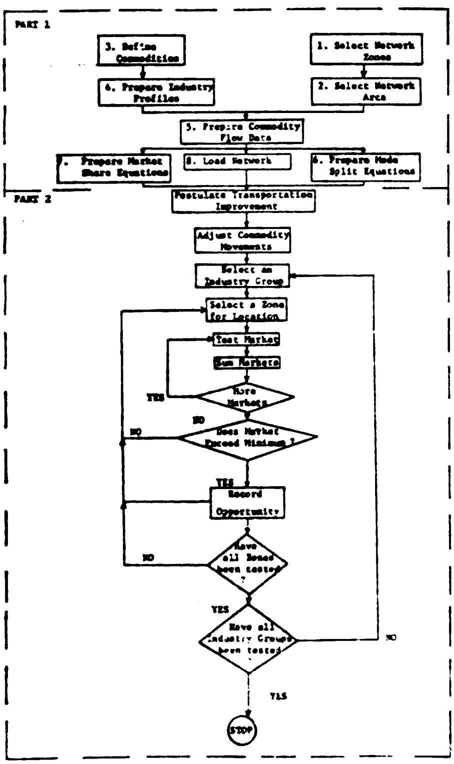

FIGURE 1

process by which different development opportunities are explored. The process is described below in terms of the Multi-State Corridor.

PART I: MODEL PREPARATION

The first part consists of eight principle steps: (1) Select network zones, (2) Select network arcs, (3) Define commodities, (4) Prepare industry profiles, (5) Prepare commodity flow data, (6) Prepare mode split equations, (7) Prepare market share equations, and (8) Load commodities on the network and test the result. Note that steps 1 and 2 and 3 and 4 can be performed concurrently. Steps 6, 7, and 8 involved substantial interaction. The entire procedure need be followed only once for each study area or corridor. Each step is described below.

Network Zones

Each zone designation consists of a boundary and a representative city or centroid. Figure 2 shows the zones used in the analysis of the Multi-State corridor. All zones include an integer number of counties. Within the corridor, zones include about ten counties and generally conform to the districts that have been formed for comprehensive planning. Adjacent to the corridor, zones consist of the input-output sectors developed by the Office of Business Economics (BEA[2]) that include twenty to thirty counties. The choice of BEAs was based on their individual homogeneity and the availability of commodity flow data. The major disadvantage of BEAs is that many cross state boundaries. As zones become more remote from the corridor, BEAs are combined to form large zones. In all, there are 111 zones in the network. Zone centroids are generally the largest city in each zone. Where the choice of a centroid is not obvious, locations of major transportation routes are taken into account.

Network Arcs

Network arcs constitute the major routes for each mode over which interzone traffic is carried. Intrazone traffic is not included in the analysis. Arc designations are related to zone size. Arcs connecting the small zones in the Multi-State corridor consist of almost all intercity cargo routes. As zones get larger, more intercity routes are omitted because they are not carrying significant interzonal traffic. For example, the highway network (Figure 3) includes Interstate, Federal Aid Primary and some state routes between the small corridor zones. In contrast, the network between large

NETWORK ZONES

FIGURE 2

HIGHWAY NETWORK

FIGURE 3

zones has few routes that are not Interstate Highways. Similarly, the rail network (Figure 4) contains most through routes within the corridor, but only principle routes outside. The water network contains major intra and inter coastal services as well as all inland waterways with seven foot channel depth or more.

Network arcs are described in terms of length, capacity, and mean speed or travel time. Where two or more routes are combined in a single arc, length and speed are determined for the higher quality route. The second route would serve as additional capacity when the higher quality route becomes congested.

Commodities

Fifty-three different commodity/industry groups have been selected for analysis. This number represents a compromise between a desire for simplicity and the need to recognize some of the important differences within two digit SIC classification. Table 1 lists the 53 commodities together with the SIC groups of which each is comprised.

Industry Profiles

Each of the 53 commodity/industry groups is treated as a homogeneous economic activity having common products, raw materials, and production methods. Using data from the Census of Manufacturers (11) cost and material flow data were compiled for each group. Table 2 shows the industry profile for group 250, Furniture and Fixtures. Material quantities, direct labor hours, indirect labor cost, energy quantity, and capital investment are associated with the industry. Material costs are location sensitive as is direct labor cost. Mean wage rate helps to identify labor skill requirements. Indirect labor is assumed to be a function of the industry organization and overhead structure and is made up of a fixed charge plus a charge that is proportional to output. Energy cost is location sensitive. Capital investment is independent of location. Taxes and transportation, of course, depend on location.

For each industry, major production and market areas are identified by zone from commodity flow data. These data, as modified, give origins and destinations by zone for each commodity group. Only zones that account for five percent or more of the production or destinations of each commodity are considered to be major production areas or major markets.

Commodity Flow Data

Commodity flow data always pose a problem for work of the type reported here. Although many pieces of commodity flow data are available, assembling

RAILROAD NETWORK

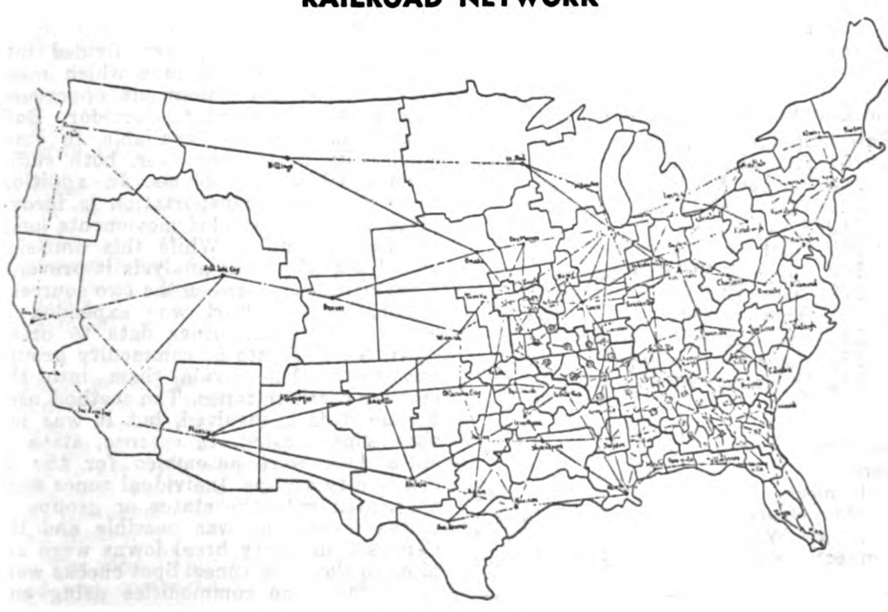

FIGURE 4

TABLE 1

COMMODITY CLASSIFICATIONS

NO.	DESCRIPTION	SIC CODES
011	Grain	011
013	Field Crops	013,016,018,019
021	Livestock	021
024	Dairy	024
025	Poultry & Eggs	025
080	Forestry	08
090	Commercial Fishing	09
101	Iron Ore	101
102	Non Ferrous Ores	102,103,104,105, 106,108
110	Coal	11,12
130	Oil& Gas Extraction	13
140	Non-Metallic Minerals	14
201	Meat	201
202	Dairy Products	202
203	Canned & Preserved Food	203
204	Grain Products	204
205	Bakery Products	205
206	Confectionary	206
207	Fats & Oils	207
208	Beverages	208
209	Misc Food	209
210	Tobacco	21
220	Textile Mill Products	22
230	Apparel	23
240	Lumber & Wood	24
250	Furniture & Fixtures	25
260	Paper	26
270	Printing & Publishing	27
281	Industrial Inorganic Chemicals	281

NO.	DESCRIPTION	SIC. CODES
282	Plastics	282
283	Drugs	283
284	Soap	284
285	Paint	285
286	Industrial Organic Chemicals	286
287	Agricultural Chemicals	287
289	Miscellaneous Chemicals	289
290	Petroleum Refining	29
301	Tires & Tubes	301
302	Rubber & Plastic Products	302,308,304,306 307
310	Leather & Leather Products	31
324	Cement	324
321	Stone,Clay,Glass&Concrete Prod.	321,322,323,325 326,327,328,329
331	Iron & Steel	331,332
333	Non Ferrous Metals	333,334,335,336 339
341	Metal Cans & Shipping Containers	341
342	Fabricated Metal Products	342,343,344,345, 346,347,348,349
350	Machinery, Except Electrical	35
362	Electrical Industrial Apparatus	362
361	Electrical Machinery	361,363,364,365, 366,367,369
371	Motor Vehicles & M.V. Equip.	371
372	Transportation Equipment	372,373,374,375, 376,379
380	Measuring Instruments	38
390	Miscellaneous Manufacturing	39

TABLE 2

INDUSTRY PROFILE — 250 FURNITURE & FIXTURES 1972

Industry Size: 8,482 Companies, 9,232 establishments

461,600 Employees

$11.4 Billion cost of goods sold

Mean Establishment Characteristics

Raw Material Needs

207	Fats and Oils	17 tons
240	Lumber & Wood	662
220	Textile Mill Products	6
260	Paper	
285	Paint	2
302	Rubber & Plastic Products	
321	Stone, Clay, & Glass Products	87
331	Iron & Steel	233
333	Non-Ferrous Metals	9
342	Fabricated Metal Products	94

Employees

Direct	
Number	46
Man Hours	82,000/year
Hourly Wage	$3.08
Indirect Labor	$95,000/year

Energy 1.9 Million BTU Equiv./year

Capital Investment $1.56 Million

the complete fabric poses many problems. Three principle data sources were used: the CTS (4), the Census of Transportation (12), and the Census of Manufacturers (11). These sources were augmented with additional data collected at the State and local levels. The CTS data as compiled by U. S. DOT were the principle source. These data are nearly complete and provide BEA to BEA movements. However, they are divided into only 20 commodity groups which mask many potential development opportunities in the Multi-State corridor. Both Census sources are available in finer commodity detail. However, both suffer from disclosure problems. In addition, the Census of Transportation is incomplete and only sampled movements longer than 25 miles. While this omission would not affect the analysis it prevents a reconciliation between the two sources.[8]

Considerable effort was expended in using Census and other data to break down the CTS into 53 commodity groups and to further divide them into the smaller corridor zones. The method used became rather involved, but it was not very sophisticated. In essence, state to state data were assembled for the 53 commodity groups. Individual zones were associated with the states or groups of states insofar as was possible and the Census commodity breakdowns were applied to the BEA zones. Spot checks were made for some commodities using employment data. In other instances, trade association data were used to modify the statistical procedure. This process focused on identifying principle commodity flows that would match the industry profile data. Small movements were assigned to a miscellaneous category that was used to load traffic on the network, but that lacked specific industry identity. The resulting origin-destination data leave something to be desired but they are probably the best that are available today. Substantial improvements can be made when the 1977 Census data are available.

Mode Split

Freight modal split work has been rather limited. Perhaps the most comprehensive study has been that made at the Pennsylvania State University (13) which confirms the conviction that flow impedances on the transportation network should be measured in terms of cost, transport time, and transport time dependability. As of this writing, the mode split model is still under investigation. The two models that appear most promising are:

$$S_{ijkm} = \alpha_{oi} + \alpha_{1i}C_{ijkm} + \alpha_{2i}t_{ijkm} + \alpha_{3i}\sigma^2_{ijkm}$$

and

$$S_{ijkm} = \exp\left(\alpha_{oi} + \alpha_{1i}C_{ijkm} + \alpha_{2i}t_{ijkm} + \alpha_{3i}\sigma^2_{ijkm}\right)$$

where:

S_{ijkm} = fraction of traffic in commodity i moving between origin j and destination k that used mode m

C_{ijkm} = cost to move a unit of commodity i from j to k via mode m

t_{ijkm} = transport time to move from j to k via mode m

σ^2_{ijkm} = variance in transport time between j and k for mode m

α_{ijkm} = coefficients of correlation for commodity i

These models are preferable to the more conventional multiplicative model because the terms, or the natural logarithms of the terms, are additive from arc to arc. It is also desirable to use coefficients that are mode abstract—that is, the same coefficient can be used for all modes.

The modal split models are being tested and compared using modal split information contained in the CTS and Census of Transportation data.

Market Share

In practice, commercial firms achieve market share for a variety of reasons other than low price. Reasons include customer service, product quality, advertising, and others that are not amenable to direct analysis. To circumvent the nonquantitative market attributes, the research took the approach that each industry group markets to its joint cost advantage.[4] Following this approach the market share that a producer enjoys in each market that he serves will be a function of the relative costs with which he and other producers can deliver products to the market.

$$M_{ijk} = f\{(p_{ij} + C_{ijkm} + \beta_{1i}t_{ijkm} + \beta_{2i}\sigma^2_{ijkm}), (p_{i\ell} + C_{i\ell km} + \beta_{1i}t_{i\ell km} + \beta_{2i}\sigma^2_{i\ell km}), \ldots\}$$

where:

M_{ijk} = market share of commodity i in market k furnished by a producer at j.

P_{ijk} = production cost for commodity i at location j.

β_{1i}, β_{2i} = coefficients

Market share data are taken from the commodity flow data which give the amount of each commodity shipped from j to k and the total amount shipped to k. Using this information and a specific function, regression techniques are used to evaluate the coefficients β_{1i} and β_{2i}. Most market share functions depend on the cost differentials between alternative supplies.

There is a close relationship between the variables in the mode split model and those in the market share model. The final versions of the two functional forms are expected to be similar.

Network Loading and Testing

Before potential opportunities for new industry can be explored, it is necessary to load all of the production, transportation, and commodity flow data on to the network and confirm that it is consistent with observed facts and relationships. The problem is modeled as an uncapacitated, multi-commodity network flow problem. All origin and destination flow requirements are with conservation of flow at each node.

$$\sum_k f_{ijk} - \sum_h f_{ihj} = D_{ij}$$

where:

f_{ijk} = flow in commodity i from j to k

D_{ijk} = demand of commodity i from node j.

The first summation represents the flow of commodity i from node j. The difference is the net outbound demand from j. The second summation is the flow of commodity i into node j.

Traffic is assigned to network arcs using a tree-building algorithm for multimodal flows. Inasmuch as present mode splits and market shares are included in the commodity flow data, these need not be calculated here.

The product of this step is a network loaded with today's traffic. This is tested by comparing assigned traffic with present traffic levels. The comparison is not very precise because of our inaccurate knowledge of freight traffic. However, precise representation is not necessary because this assignment merely provides a background for Part 2 of the analysis.

PART 2: EXPLORING OPPORTUNITIES

The Part 2 analysis consists of a systematic exploration of development opportunities with different combinations of transportation improvements. The three principle steps are (1) postulating transportation improvements, (2) adjusting normal commodity movements, and (3) testing for new development opportunities. This set of steps is typically performed many times.

Transportation Improvements

Although transportation improvements are the desired output of the research, there is no proven method to develop improvements analytically for the case of uncongested networks. It would be possible to develop a heuristic for changing transportation impedance, however, arbitrary changes not related to specific technology would have little meaning.

Transportation improvements can be postulated for any of the corridor arcs. Some improvements are based on apparent deficiencies, others are keyed to specific improvement ideas. The entire process is based on careful analysis of past results and speculation about future opportunities.

Each new arc is described in terms of cost, travel time, and travel time variance. Cost calculations are initially based on expected usage and later corrected to actual usage. Costs are sufficiently insensitive to small increments in volume that one correction is normally sufficient. Travel times are based on uncongested flow as are other arc travel times.

Intermodal transfer opportunities are also postulated by including node transfer delay times and node transfer costs. As with arcs, costs are corrected to conform to actual volume.

Adjusting Commodity Movements

New transportation improvements will benefit existing traffic as well as traffic originating at new facilities. It is therefore necessary to consider beneficial changes to existing traffic before exploring developmental opportunities. New transportation improvements can provide low cost arcs that will modify the shortest path followed by a fraction of commodity flow assigned to a particular mode. These improvements are identified as part of the routine shortest path calculation. New transportation improvements also provide mode change opportunities by which single mode shipments are changed to intermodal shipments. Inasmuch as no optimizing technique has been developed to identify intermodal shipments, these are treated with a heuristic that explores intermodal opportunities for shipments that cross or parallel the new improvement. The heuristic first checks the change in route length necessary to use the new facility. If the change does not exceed an arbitrary limit, intermodal routes are checked. For some types of transfer facilities only specified commodities are checked.

Revised shortest route change costs at which some facilities deliver to affected markets. This in turn upsets the market share calculations. It is therefore necessary to revise the market shares. Some zones or facilities lose output; others gain. The product of the commodity flow adjustments is a new equilibrium that represents adjustments due to the new transportation improvement or improvements.

New Development Opportunities

New development opportunities are explored in an exhaustive fashion. In the extreme case, each of the 53 industries is tested in each of 40 zones of the Multi-State Corridor, resulting in 2120 determinations. Generally, there are good reasons for excluding some commodities and some zones so that the actual number of determinations is somewhat smaller. However, the procedure is the same regardless of the number of determinations.

Given a commodity and a zone, a minimum economic sized facility is postulated for the zone and production costs are estimated. Then shortest path single or intermodal routes are calculated from the new facility to each of the markets for that commodity. A market share is computed for each market and extended by the size of the market. If the total market identified for the new facility exceeds the minimum economic size, then an opportunity has been found. If the total market does not equal the minimum economic size, then an opportunity has not been found and the commodity and zone are discarded. In this latter case, the next likely zone is postulated for the commodity and the analysis is repeated.

When all likely zones and commodities have been explored, a set of development opportunities will have been identified. A heuristic procedure is used then to select those opportunities that will have the greatest impact on the overall objective function while meeting zonal constraints regarding labor and land. More detailed development programs can be investigated by combining development opportunities into sets and investigating their market viability. As opportunities are combined, more traffic is produced for the new transportation facilities and cost goes down. The ultimate outcome is a joint set of transportation improvements and development opportunities.

CONCLUSION

A procedure has been devised and developed for identifying economic development opportunities in underdeveloped areas. The procedure can measure the impact of new transportation facilities including intermodal movements on these new development opportunities. Finally, the procedure can be used to structure a joint transportation and industry development program.

The procedure depends on the use of commodity flow data that are unavailable today without a great deal of work and many approximations. However, data improvements expected in the near future will enhance the value of the procedure.

Additional work is needed on modal split and market share models and on the heuristic for exploring intermodal opportunities. However, the results to date are sufficiently promising to full justify the additional work.

FOOTNOTES

1 Use is also made of the Standard Transportation Commodity Classification (STCC).

2 Basic Economic Area.

3 The 1977 Census of Transportation will sample from all shipment distances and it will be reconciled with the Census of Manufacturers. This is an important improvement.

4 In fact, several industries, e.g., petroleum refining, do market in in this fashion. An energy short future may require more industries to do so.

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