OECD FEB 3 1967

PN-ABI-402
72258
70

HARVARD TRANSPORTATION AND ECONOMIC DEVELOPMENT SEMINAR

Discussion Paper Number 40

THE ROLE OF TRANSPORT IN DEVELOPING COUNTRIES: A DEVELOPMENT PLANNING MODEL

Paul O. Roberts

Harvard University

May 6, 1966

Table of Contents

Preface.....i

1. Introduction.....1

   A. The Problem of Defining Goals.....1

   B. Control Variables in System Design.....3

   C. Functional Components of Systems Models.....4

      1. Forecasting Demand.....4

      2. Predicting Network Utilization.....6

      3. Determination of Cost-Performance Characteristics.....6

I. The Macro-Economic Model.....8

   A. The Structure of the Macro-Economic Model.....8

   B. Use of the Macro-Economic Model.....13

   C. Data Considerations.....14

The Transport Model.....15

   A. Scope and Requirements.....16

      1. General Requirements.....16

      2. Information Required by the Model.....17

   B. The Need for Disaggregation.....18

   C. Principal Features.....19

      1. Disaggregation.....21

      2. Use of the Network-Link File.....22

      3. Determination of Modal Choice and Network Routing....25

III. (con't) C.

4. Distribution Patterns.....26

5. Assignment.....27

6. Backhaul.....29

7. Modal Cost-Performance Submodels.....30

8. Pricing Policy.....32

9. Systems Performance Measures.....32

10. Vehicle Requirements and Availability.....33

D. Data Considerations.....34

IV. The Use of the Models in Planning and Decision Making...36

Appendix.....37

Preface

The research described in this discussion paper is being conducted as a part of the Transport Research Program sponsored by The Brookings Institution with funds provided by the U.S. Agency for International Development.

One of the major results of the research effort has been the development of simulation models which allow the development planner to test alternative transport plans and their effect on economic growth. Two models, the Macro-Economic Model and the Transport Model have been developed. This paper deals principally with the Transport Model. A more complete description of the Macro-Economic Model can be found in Discussion Paper No. 32 prepared by David Kresge. The counterpart for the transport sector is included as an appendix in this paper. The paper concerning the evaluation model mentioned in Section IV is forthcoming.

I. Introduction

A primary problem in most underdeveloped areas is that they are not developing, or at least not at a satisfactory rate. The extent to which this is related to transport is, of course, a fundamental question. If no investments are being made in the transport sector, then this is a fairly easy question to answer. A complicating factor is that it is difficult for private capital to supply the fixed investments needed in transportation, both because of the magnitude and because of the risk associated with predicting the demand for these facilities. Thus, if government has not taken the initiative in providing facilities, there may well be a shortage which is serving as a constraint upon balanced and sustained growth. More elusive, however, is the question of the extent to which changes in the transport system can guide development. Transportation alone cannot "cause" economic development of course. The nature of transport is such that goods or people must be moved before any real value is obtained and demand is derived. Encouraging this movement before it is economically viable merely leads to distortion of the economy.

A. The Goals Problem

A problem that is typically encountered in dealing with transportation in the more developed countries is that the

goals or objectives are not explicit, if, indeed, they exist at all. Lack of clearly stated objectives, increases the difficulty of dealing rationally with the situation. In fact, the question frequently becomes "what is the problem?" This is complicated by the fact the goals respond to experience and expectations, which may change as development occurs.

At first glance, the developing country appears to be spared the "no objective" problem. Because it is underdeveloped, there is a ready-made objective, namely economic development. However, there are many dimensions to development and a number of measures by which development is typically evaluated--GNP, value added, regional income, and regional employment, to name a few. As Lefeber points out, "Economic Development implies that national income grows at a faster rate than population and that the benefits from growing national income lead to improvements in the standard of living of low income groups. Hence, not only income growth, but income distribution is involved."[1] We are, therefore, still left with a problem in definition of objectives.

---

[1] L. Lefeber, "Economic Development and Regional Growth," Chapter 6 of Transport Investment and Economic Development, Edited by Gary Fromm, (Washington, D. C.: The Brookings Institution, 1965).

B. Control Variables in System Design

Once the "objective barrier" is solved the next question is typically, can the system be manipulated to produce desirable results? Though conclusions can never be final in a general sense, the indications are that the transport system does yield to control primarily by the government. Thus control can become a conscious tool by which public aspirations such as economic development can be furthered. This requires a rather complete knowledge of the transport system and its response to certain changes.

This study has focused to date on the development of computer simulation models by which these elements of control and their effects may be studied. What are the underlying mechanisms and their variables? Which variables are controllable and by whom? To what extent is the system stochastic? Are there strategies which dominate? These are the questions the models have been designed to answer.

The models which have been developed may also be useful in the planning process though the steps between research and planning are admittedly large. It is not entirely satisfactory to think in terms of a single goal or objective. Not everyone has the same viewpoint because of their livelihood, their location or their personal affiliations. Real world planners are more often faced by

multiple, even conflicting objectives arising out of these different viewpoints. Simulation models can by proper design be used not only for the prediction of the consequences associated with alternative planes but also for their evaluation. Prediction and evaluation are separated within the models in order that the consequences of a plan will not be confused with value judgments about these consequences.

C. The Functional Components of Systems Models

There are certain functions which must be performed in conjunction with the use of every transportation system model. Basically these are 1) the forecasting of demand for transportation; 2) the prediction of the way in which the network will be used; and 3) the determination of the resultant cost performance characteristics of individual links in a network. See Figure 1.

Forecasting demand

The most difficult and elusive of the three phases is the forecasting of demand for transportation. By demand the quantity and location in space of specific requirements and supplies of each good is what is meant. This is to be contrasted to the usual economic definition. What the economist usually implies when he says demand is the price

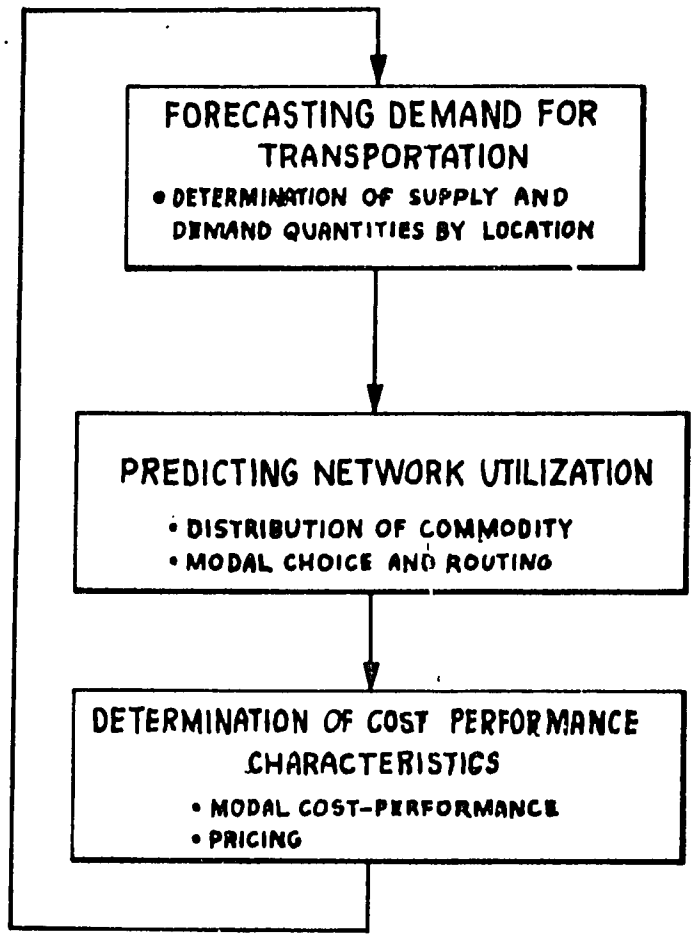


FIGURE 1 FUNCTIONAL COMPONENTS OF SYSTEMS MODELS OF TRANSPORTATION

quantity relationship rather than specific amounts.

2. Predicting Network Utilization

The prediction of network usage can be thought of as consisting of two parts. First, the determination good by good of who buys from whom. This depends, of course, not only on the supply and demand quantities, but also on the difficulty and cost of shipping between between given points. This question is closely allied to the over-all demand computation but treatment of it in this way is of course arbitrary. This phase is frequently referred to as "distribution."

Secondly, network usage involves the determination of modal choice and routing. The two are frequently considered separately. Modal choice has even been treated in conjunction with demand. They have, however, been treated simultaneously here for computational convenience. The purpose of this phase is the prediction of network flows for each of the links in the system as well as flows between points by commodity.

3. Determination of Cost-Performance Characteristics

As the flows on a transportation network change, the cost-performance characteristics change. Nowhere is this

more evident than the rush hour traffic jam which occurs on most city streets. Flows on the transport networks of developing countries react to changes in flow. There are major differences, however. In fact, as flows increase, unit costs may actually decrease and service times improve. These relationships vary from mode to mode and within modes there may be considerable differences given variation in basic link characteristics such as design speed, width of road, number of trucks, etc, or variation in type of equipment. This phase attempts to determine the basic link performance of each link as subcomponents of the over-all system. Since the price for using transport services may not be identical to the costs, the effects of given policies must also be introduced at this point.

The purpose of this paper is to present a necessarily abbreviated description of the models which have been developed. They correspond to the functional components of transportation systems shown in Figure 1, and consists of a Macro-Economic Model, a Transport Model and a series of Technological Models for predicting the cost-performance characteristics of each of the transport modes. Because of the focus on transportation the primary emphasis will be on the Transport Model, though the others are equally as sophisticated as well as independently useful. The Technological Models are actually embodied within the framework of the Transport Model and will not be discussed independently here.

Demand for transportation is for the most part a derived demand. That is, the basic demand is for a good located in a specific place. If the good is already in that place, there is no transport demand. Transport is merely a spatial transformation. Thus, the problem of predicting the demand for transport at a particular point is in actuality a problem in predicting the demand for various goods at that point. The attributes of the transport required such as time, cost, etc., merely add to the attributes of the good itself.

It goes without saying that the tasks of predicting these needs (transportation) is not easy. One must in fact know the needs of the entire economy. It is not enough to be able to predict only final demands for goods and services, since the intermediate goods required in production for final consumption must also be transported. There are, in addition, import and export products from trade with other countries. In order to do the job, an entire model of the economy is needed. What is more, the model must be able to predict needs on a regional basis. The development of such a model is itself a very large undertaking.[2,3]

---

[2]David Kresge, "A Simulation Model for Development Planning." Harvard Transport and Economic Development Seminar, Discussion Paper #32, Nov. 1965.

[3]Brian Martin and Charles Warden, "Transportation Planing in Developing Countires," Traffic Quarterly, Jan. 1965.

The scope of the Macro-Economic Model is somewhat broader than the use to which we suggest putting it here. In this instance, we are viewing it only as a "demand model" though its potential for over-all development planning must be apparent to the reader. It should be pointed out that the Transport Model does not require the use of the Macro-Economic Model in order to be operative, since it requires only the regional supply and demand for each industry. Its use is greatly enhanced by it, however.

The Structure of the Macro-Economic Model

The Macro-Economic Model is used to simulate the functionings of an entire economy. This requires a great deal of information and also a great deal of simplification since the economy of even an underdeveloped country is extremely complex. The basis of the Model is a national input-output table which can be used to determine the amount of each constituent input required to produce a single unit of output of each commodity. The input-output table thus incorporates by means of its technological coefficients the inter-industry transactions which will be generated by any given set of demands for final products.[4]

---

[4]For an introduction to the use of input-output analysis see William H. Miernyk, The Elements of Input-Output Analysis, (New York: Random House, 1965).

The model is an econometric computer model. In addition to the input-output table, it consists of a series of equations expressing the inter-relationships between the environmental variables (which adjust to fit various economies), the program parameters (by which the model is calibrated), and the controllable variables (by means of which the planner can influence over-all growth). A schematic representation of the model is shown in Figure 2.

The model is designed to perform its simulation over time and is, therefore, aged from period to period in one year increments. For each year, a final bill of goods in each region is determined based upon private consumption, investment in plant, investment in inventory, and government expenditures. Exports are added to the sum to obtain a national final demand. Of these inputs, government expenditures, exports and a portion of investments are all specified exogenously so that they may be controlled by the planner. Consumption is determined based on the wages and dividends from the previous year. The output of each industry is now obtained by means of the input-output computation carried out for the nation as a whole. The output is then regionalized by means of an empirically weighted function involving the regional output of the good in the previous time period, regional profitability, and regional

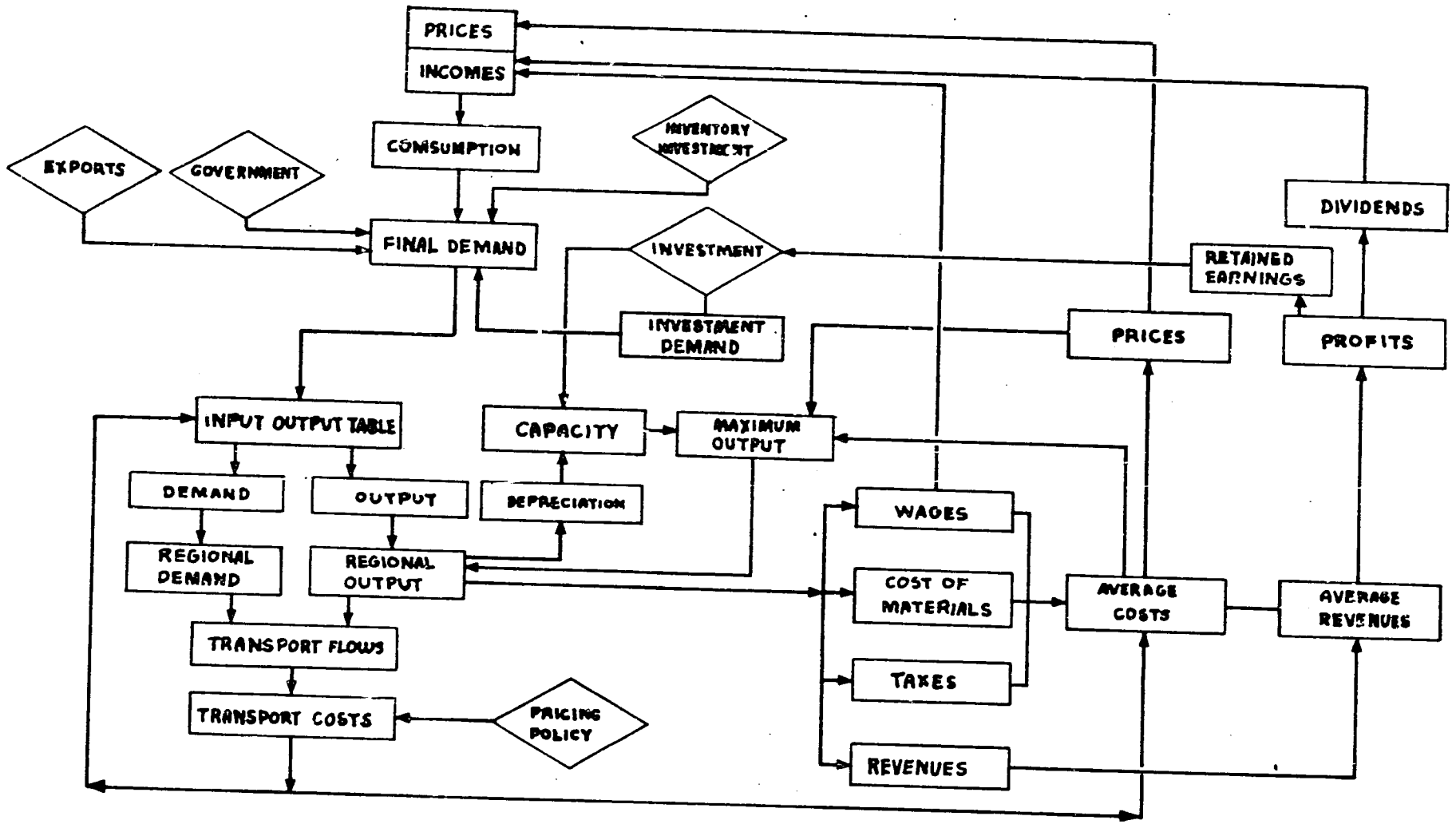


FIGURE 2 THE MACRO ECONOMIC MODEL

capacity. Thus, regions that have production do not suddenly lose it if, for some reason, their profitability drops.

Regional output is now used in the computation of regional wages, depreciation of plant, revenue, cost materials, and taxes, from which profits, retained earnings, dividends, and average revenue is determined for each commodity in each region using last period's prices. Regional demands are also developed by adding regional final demands to intermediate good demands which are easily obtained by multiplying regional output by the technological coefficients in the input-output matrix.

The new price for each commodity in each region is developed using average supply costs, marginal supply costs, average transport costs, and specific sales taxes, once again weighted empirically so that the model may be adjusted to fit unusual conditions.

A simplified transport sector allows the model to be used alone, if necessary. This portion determines interregional flows by means of a simple gravity model. Flows are distributed between regions with excess output and those with a positive demand in proportion to the size of the demand and inversely proportional to the cost of production plus transport, weighted by an exponent and normalized so

that supplies will equal demands. The simplified transport sector also takes into account congestion for those interregional links which exceed their given capacities.

During each time period a recomputation is made of the input-output coefficient for transport for each commodity. It must agree closely with the one which has been used by the model. A balance of trade computation is also made.

The result of the application of the model for one year is a complete simulation of regional production and consumption for that year. From the viewpoint of the tranport model, the result is the dollar quantity of regional supply, demand, and production costs for each of the industries in the input-output table as well as imports and exports.

B. Use of Macro-Economic Model

If for no other reason the use of the Macro-Economic Model is justified on the grounds that it furnishes the Transport Model with a source of complete and consistent data on production and consumption through time. If the input-output coefficients are correct, then national totals will be good. Regional production, if properly allocated, uses these same coefficients to generate consistent patterns of consumption.

C. Data Considerations

The data situation in developing countries is generally bad. The more underdeveloped the country, the worse the data. In some countries even the estimates of total population are tenuous. There are frequently no national systems of production accounts and, consequently, no published input-output tables. In general, however, small input-output tables of five to twenty sectors do appear to be available or they may be constructed using available statistics. More detailed product accounting is likely to be spotty, if it exists at all.

Data gathering for the Macro-Economic Model is perhaps more exacting than that for the Transport Model since its compact nature requires that it be internally consistent and complete. Data should, if possible, be obtained for more than one period in time to serve as a check. Where data are presently unavailable, then programs to obtain the needed figures may be initiated. In the meantime, however, approximate values may be estimated in order that work may proceed. Later, sensitivity analyses of these missing variables may be undertaken to determine the overall accuracy required in their estimation and the importance to model results. It appears, in general, that intuition must be used freely where necessary.

When working with a system which is as large as the economy, the final consequence of a series of smaller

educated guesses constrained within over-all boundaries can be counted on to produce results which are superior to those of individual final stage guesses because of the internal consistency which is built into the model.

III. The Transport Model

The transport Model is also a computer simulation model. It is not statistical or monte-carlo in nature but deterministic for the most part. It does contain stochastic elements. This seems desirable in view of the uses to which it is expected to be put. It will be important to know the mechanical details of the assumed interrelationships. It would be embarrassing, for example, to get answers for which one could not later verify the sequence of events within the model which led to the answers obtained and their over-all magnitude.

This model, like the Macro-Economic Model, is written in the FORTRAN IV language for an IBM 7094 computer. This somewhat determines its over-all capability and size. Reasons for selection of the system and language are many and subjective but basically it was felt that for the present at least, simulation languages were restrictive, particularly in terms of size.

A. Scope and Requirements of the Model

The Transport Model has been conceived in conjunction with the Macro-Economic Model. The Macro-Economic Model furnishes basic production and consumption data which is used as input to the Transport Model. The Transport Model in turn returns transport costs and distributional patterns to the Macro-Economic Model. It also appeared desirable to design the model so that it might be used separately.

I. General Requirements

The basic requirement of the Transport Model is that it should describe how the producers of commodities would use a given transport network to reach what they consider to be desirable markets. This implies a capability for simulating the behavioral aspects of market selection. The Model must be able, therefore, to approximate the aggregate behavior of a number of individuals, each acting in his own self-interest. If this is properly done, commodity by commodity, it will allow the resultant network flows and the consequent costs to be determined for both using the network and for supplying transport facilities and services.

The principal means by which control can be exerted on the Transport Model is through the selection of system

additions or changes, including detailed changes in the characteristics of each link, and the specification of the number and type of vehicles available. These correspond closely to mechanisms available to government in the real world. A second feature of the Model is the inclusion of a transport pricing function. Since another important means of governmental control in developing countries is exerted through controlling the price of using the facility, it was also incorporated into the model.

2. Information Required by the Model

In order to accomplish the basic task of determining network flows a number of inputs are required. These include the following:

1. Regional demands for each commodity for both industrial and individual consumption in dollars.
2. Regional supply of each commodity in dollars.
3. Regional unit production costs by commodity in dollars.
4. Physical characteristics and transport preferences of each commodity.
5. Topology and characteristics of the transport network.
6. Characteristics and physical specifications of each transport mode.
7. Transport pricing policy in the form of a rate table by mode.

These inputs are obtained from a variety of sources. Each will be examined in more detail in the sections which follow.

B. Need for Disaggregation

Transport requirements within the model must ultimately be determined by converting dollars of commodity supply and demand into tons, and tons into vehicular needs. The level of aggregation of the economic data available whether the Macro-Economic Model is used or not makes this extremely difficult. Transport modal preference and routing is also affected since individual transport service requirements for a commodity as highly aggregated as for example "manufacturing" are impossible to determine. There needs as well to be differentiation within each region since most regions will be larger than is desirable from a transport standpoint. Finally, the seasonality of supply and demand and its consequent transport effects are completely lost if figures for an entire year are used.

The result is that disaggregation is essential. Three types of disaggregation have been incorporated into the Transport Model: regional, subcommodity, and seasonal. Each of the basic supplies and demands can

be subdivided within the region into a number of subcommodities, each with a separate seasonal production schedule and a different set of preferences for transport service.

C. Overview of Principal Model Features

The structure of the Transport model is relatively straightforward. The transport network is defined in terms of a link-node graph. Cities and transport interchanges are represented by nodes. The links represent real-world transport interconnections such as roads, railroads, waterways, etc.

Model operations on this network can be described conceptually as a step-by-step computation, carried out for each commodity and consisting of disaggregation into subcommodities, the determination of distribution patterns by subcommodity, and finally the selection between each origin and destination point of the best choice of mode and route over the network. The resulting trips are successively accumulated on each of the links of the network to show link utilization. Each link is then analyzed separately depending on its mode to determine its resulting cost-performance characteristics. The costs are revised to reflect the pricing policy which is in effect. Finally, cost-performance characteristics are stored for use during the next time period. See Figure 3.

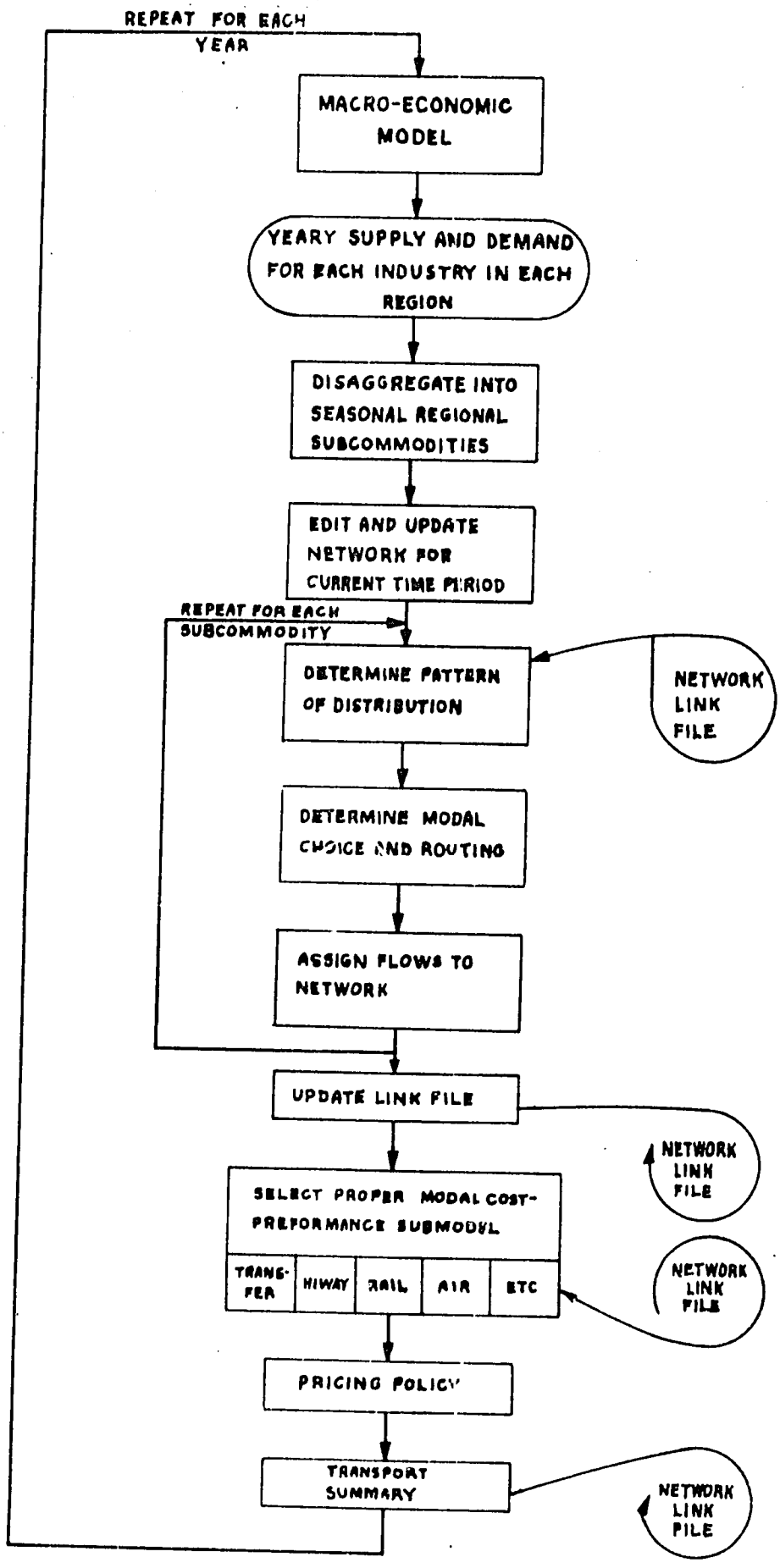


FIGURE 3 THE TRANSPORT MODEL SHOWING ITS LINKAGE WITH THE MACRO-ECONOMIC MODEL

1. Disaggregation

The yearly supply and demand for the products of a specific industry can be disaggregated rather simply by the specification of disaggregation factors within each region. If, for example, one knows that seventy per cent of the agricultural production of a given region is rice, ten per cent is fruit, and twenty per cent are other agricultural products, then one has in effect disaggregated agricultural supply for that region. It is only necessary to formalize this procedure and to relate the quantities produced to specific nodes of the network in order to make it useable by the transport model. Similarly, a seasonal disaggregation factor specifies the percentage of total subcommodity production which is forthcoming during each season.

Demand for each subcommodity is automatically disaggregated in the proportion which regional demand for the parent commodity is to total demand for that commodity. More sophisticated demand disaggregation is possible but has been ignored for the present.

By disaggregating supply and demand, the ability of the transport model to capture the essential features of the production and consumption process within each region is greatly enhanced and the model as a whole is therefore

improved. Perhaps most importantly the model is given information which makes possible the handling of seasonal fluctuation. Without disaggregation, the usefulness of the entire transport model could be questioned since sufficiently large input-output tables would be extremely hard to come by and computationally difficult even if they could be made available.

The information necessary for the carrying out of disaggregation does not usually exist as a specific body of information. However, examination of regional production statistics will allow a great deal of the disaggregation to be done on a quantitatively sound basis. In many countries the data to do this presently exists. In Colombia, for example, national statistics are given by region and are readily usable. Since disaggregation factors are specified in percentages, it is not difficult to make an educated guess at factors where actual figures do not exist.

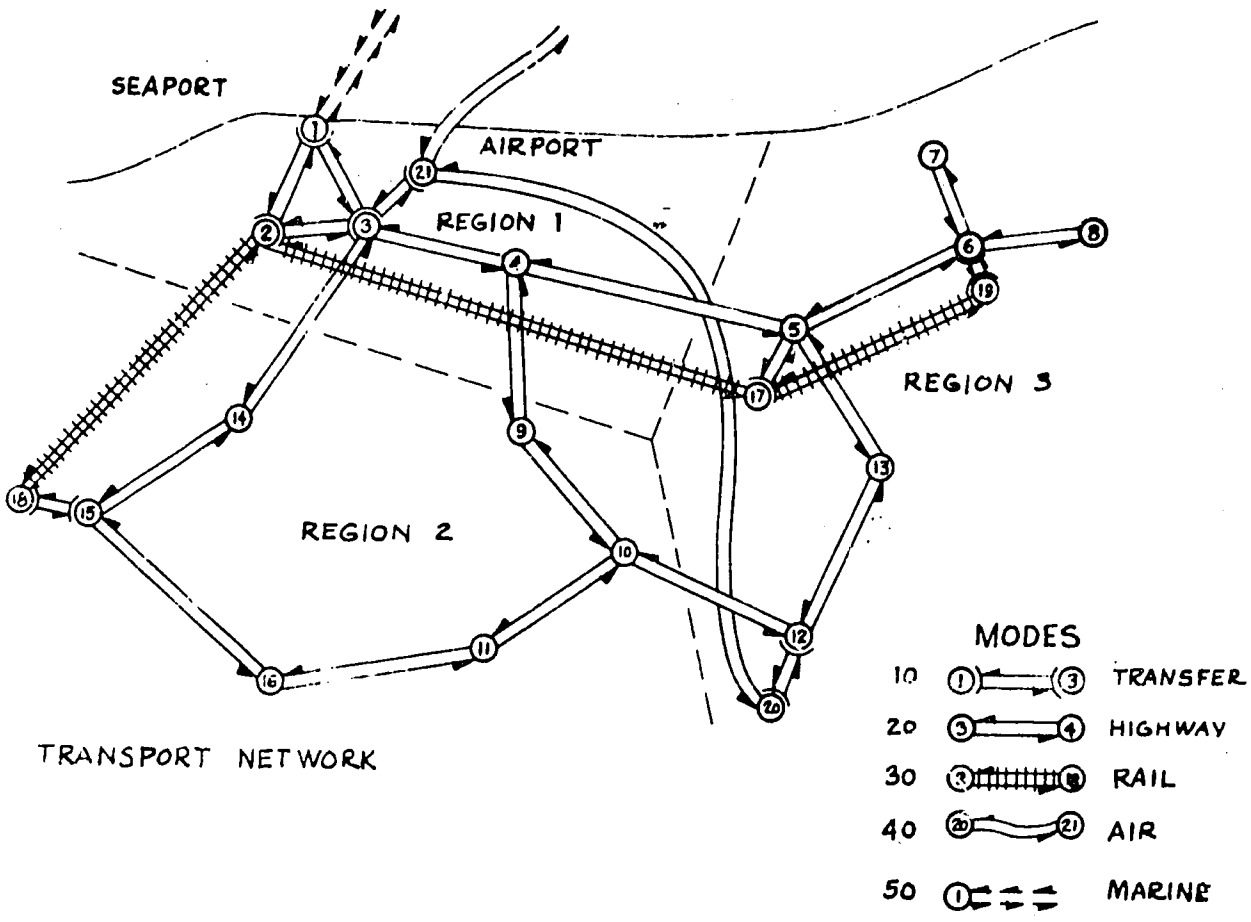
2. Use of the Network Link File

The Link File is the place where the link-node network for all modes is actually kept. It is stored link-by-link along with information concerning the physical characteristics of the link, the volume of flow on that link by season, and information regarding the link's cost-performance

characteristics, also by season. This information is updated each time the model is run and serves both as input to and output from the model. See Figure 4.

The purpose of the network flow phase of the Transport Model is to fill in flow volumes on the Link File using the cost-performance values from the corresponding season of the previous year. The link cost phase then uses the link volumes and physical characteristics as input to the modal cost-performance submodels. These simulate the actual flow of vehicles over the link under the conditions described in order to determine an updated set of cost performance values for use during the next time period.

Vehicular flow is broken into five classes, each of which is represented by a typical vehicle. These five classes are: bulk, general, special, common carrier passenger, and private passenger. The corresponding vehicle types for highway travel are: combination unit truck, single unit truck, special truck, bus, and auto. Each subcommodity is assigned to a particular class of carrier. For example, coal traveling over a highway would travel by bulk truck and over rail by bulk rail vehicle. Bulk commodities travel at bulk rates. Volume of flow and cost-performance entries for each of these classes of vehicle are carried in the Link File.



THE NETWORK LINK FILE

I NODE	J NODE	MODE	LCV LINK CHARACTERISTIC VECTOR	LUV LINK UTILIZATION VECTOR	LPV LINK PERFORMANCE VECTOR
1	2	10	. . . . .	. . . . .	. . . . .
2	1	10	. . . . .	. . . . .	. . . . .
1	3	10	. . . . .	. . . . .	. . . . .
3	1	10	. . . . .	. . . . .	. . . . .
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
3	4	20	. . . . .	. . . . .	. . . . .
4	3	20	. . . . .	. . . . .	. . . . .
4	5	20	. . . . .	. . . . .	. . . . .
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.

FIGURE 4 NETWORK REPRESENTATION OF THE TRANSPORT SYSTEM AND ITS CODING IN THE NETWORK LINK FILE

3. Determination of Modal Choice and Network Routing

The shippers choice of mode and routing is assumed to depend on a number of variously important factors. The subjective evaluation of the factors by the shipper vary from subcommodity to subcommodity. A measure of the relative rating of each link from the viewpoint of the shipper is obtained by taking the linear combination of the cost-performance factors P_i and the corresponding set of value weightings V_i assigned to each factor by the shipper. That is,

$$R = V_1P_1 + V_2P_2 + \ldots\ldots + V_nP_n$$

Each element in the cost-performance vector corresponds to the quantity of a particular physical attribute experienced as a result of traveling over the link under consideration. In our case, the cost-performance factors P_i, referred to as the Link Performance Vector, are obtained from the Network Link File. The elements of the vector incorporated in the present model are waiting time, travel time, standard deviation of travel time, probability of loss and out-of-pocket cost to the shipper. The value weightings V_i assigned to each factor by the shipper are known as the Commodity Preference Vector. The multiplication of the two vectors produces the R-factor rating of the link from the

viewpoint of the shipper. The R-factor is in effect the cost to the shipper of routing his subcommodity over the link.

At the time network routing is performed, the transport network is defined over-all without regard to mode. That is, the entire transport network is available to be shipped over. Thus, a particular subcommodity may be routed over any link in the system. It chooses that path between origin and destination which results in the minimization of the R-factors previously obtained. Those links with high R-factors will, therefore, tend not to be chosen. The computation of minimum paths is performed by means of a very efficient minimum path algorithm. The cumulative R-factors which represent total cost for transporting between each origin and destination are saved for use in the distribution procedure.

4. Distribution Patterns

The pattern of interregional sales is determined by the use of one of several commodity distribution models. Total supply and demand figures for each subcommodity at each node are known. The problem becomes one of distributing from a few supply sources to a larger number of demand points. The choice of distribution models and its

parameters is made by the user for each subcommodity individually. Thus, a wide variety of special conditions can be taken into account. Although only two distribution models are currently available, the Transport Model can accommodate any number of others merely by their addition.

The two currently available distribution procedures are the linear programming transportation model and an inverse impedance model. The programming model results in producers supplying only a limited number of markets with no cross hauls at all, since this is inconsistent with serving demands at minimum cost. The inverse impedance model results in each producer supplying every market. In both models, supply exactly balances demand so that there are no shortages or overages.

5. Assignment

Assignment of flows to the network can be done as soon as flow volumes have been calculated in the distribution process. Flows are routed along the minimum paths determined earlier. This is done by retracting the paths link by link allowing the flow quantities to accumulate. See Figure 5. Up to this point flows have been carried in terms of dollars per season. Once the distribution process is completed, flows are converted to tons by divid-

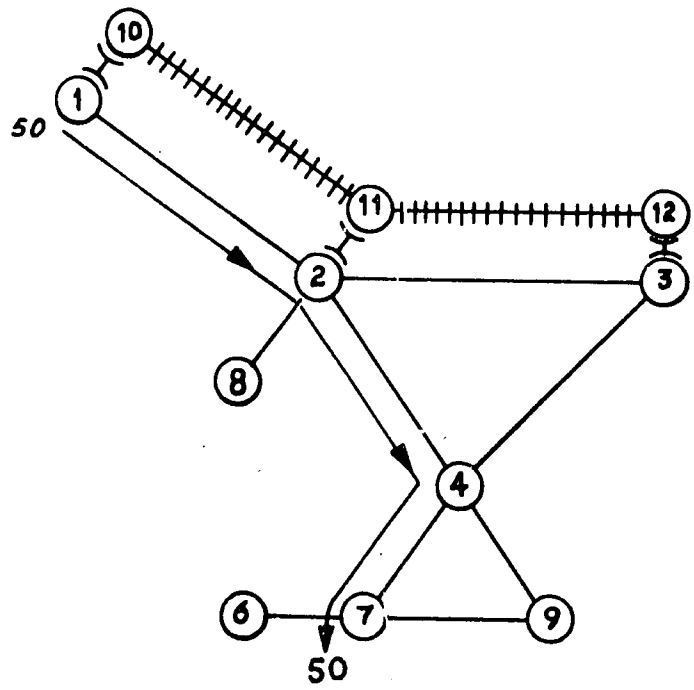


FIGURE 5 ASSIGNMENT OF TRIPS OVER THE NETWORK

ing by the value of the commodity per ton and the days per season. As the flow paths are retraced in the assignment process, the flow volumes are divided by the payload of the appropriate vehicle class to obtain flows in number of vehicles as well. Network turns are also carried so that the volume of vehicles in each of the turning movements at nodal intersections may be determined. This allows the estimation of switching and interchange times, if needed.

Once all assignments have been made for all subcommodities for a season, the Network Link File is updated with the seasonal volumes. The entire procedure is then repeated for each season in turn until all assignments for the year have been made.

6. Backhaul

One very important determinate of over-all system costs is the degree to which vehicles must be returned empty in order to secure another load. This "backhaul" is also a major item in the determination of load factors, though not the only one. Vehicle scheduling also plays a role here since vehicles may be forced by their schedules to leave before they are full. Since the cost of returning the vehicles empty must be borne by someone, it may be charged off as an increase in costs to all system users or it may be transferred specifically to the "forehaul" shipper.

There are a number of ways in which backhaul could be explicitly incorporated into the model. The approach which we have employed here is perhaps the simplest. Backhaul is computed by simply checking the number of forehaul vehicles traveling in each direction and selecting the larger. The difference between the two is then the number of vehicles which must be backhauled.

In developing countries, the assumptions required by this scheme are probably fairly good. Both road and rail networks are not well articulated and trips tend to be forward and back rather than circulating over the network. Larger rail systems may in fact tend to exhibit a sort of "brownian movement" with respect to box cars but the limited extent of the network in developing countries tends to inhibit this.

7. Modal Cost-Performance Submodels

A distinctive feature of this model is the employment of cost-performance submodels for the simulation of operating conditions on each of the links. There is a separate submodel for each mode. As each link pair in the network link file is read, the appropriate modal submodel is called and simulation begins.

The individual submodels use the physical characteristics given in the Link Characteristic Vector and the link volumes and tonnages from the Link Performance Vector as input, along with vehicular costs and operating characteristics contained internally. The final result is an updated Link Performance Vector containing values for waiting time, travel time, standard deviation of total time, probability of loss, and cost to provide the transport service.

Sophisticated submodels have already been developed for rail, highway, and transfer links. Unsophiscated models presently fill in the gaps for water and air and can be made to handle any of a number of fairly exotic modes as well, such as camel caravans, herded cattle, etc.

Each of the models goes about the simulation in a different way. The rail cost-performance model, for example, computes running speeds based on available tractive effort determined from average and ruling grades, number of locomotives, and train make-up. It then reduces these speeds by the consideration of the number of sidings, type of signal system, and type of switching controls and traffic levels in the opposite direction. Costs are determined based on an equal number of considerations.

. Pricing Policy

The incorporation of a pricing policy routine into the model enables a number of different exogenously determined pricing policies to be placed into effect. The routine works with an externally specified rate table. The table differentiates rates by mode and by class. Modal subsystems may also be identified. There may be, for example, two rail systems in the country each with different ownership as there was in Colombia until the last few years when the Colombian National Railroad annexed the departmental railway of the Departamento de Antioquia. It may be desirable to establish different rate structures for each. This can be accomplished.

The rate table also allows the possibility of a costing structure based on marginal cost pricing. In this case, the price is given as a direct function of the cost of providing the service determined by the modal cost-performance submodels.

9. Systems Performance Measures

In addition to providing performance measures for the individual transport links provision has also been made for measures of performance of the entire system. Such

aggregate items as total waiting times, travel times, transfer time, vehicle miles, ton miles, revenues, and costs for the entire system are computed.

10. Vehicle Requirements and Availability

The ease with which one can acquire a vehcile to begin a journey,or to continue it once interrupted,is determined to some extent by vehicle utilization. In situations where the requirements for vehicular time approach closely the available hours, then network delays may be expected. Delays are most often encountered at transfer points where travel by one mode is terminated and travel by another originates. Delay is due principally to waiting for the new vehicle. Similar delay is experienced at trip origins but probably not as badly. Network vehicle requirements can be computed by summing travel time at all links, waiting time wherever it occurs, loading and unloading time at transfer points, and at terminal points. To this is added vehicle maintenance and downtime. Available vehicle hours are determined by simply multiplying the number of vehicles by the number of hours they work per day and the number of days in a season. This enables us to determine a ratio of requirements to availability. The ratio is used in the modal transfer cost-performance submodel for the determination of travel delay.

D. Data Considerations

The data requirements for the Transport Sector are considerable and obviously will require large expenditures of time and effort on the part of the investigators.

Regional data may or may not be in existence and where they do exist, production may not be broken down by subregions or cities. Published regional consumption figures appear to be almost impossible to obtain. One reason may be that producers are reluctant to indicate to whom they sell. Perhaps takers of statistics have neglected to ask. The result is the same. It is easier in general to estimate consumption than production, since if one knows the population and production statistics for a region, the basic inputs required for both industrial and human consumption can be determined by means of input-output coefficients.

Engineering data and vehicle flow statistics are generally easier to obtain. Many developing countries have in the past commissioned engineering firms to prepare transport plans, often as a result of pressures applied by international lending agencies. Because of the nature of the firms engaged in the study the published

plans are often a wealth of engineering information and are valuable resources.

For those countries lacking such a study, data collection presents a formidable problem. National railroads and airlines are generally good sources of interregional flow statistics, but interregional goods movement by highway are rarely available. Inventories of existing transport rolling stock may either be available or may be readily estimated, particularly for such things as numbers of trucks, locomotives, etc. Fixed facilities are, however, another matter. Even maps of existing roads and their types are frequently in error although aerial photography furnishes a good means for obtaining needed information in most cases.

Data must, in general, be gotten by bits and pieces. First hand knowledge gained by going to the country and talking with the people is invaluable for filling in missing information. There is perhaps no substitute for seeing the conditions that actually exist. Statistics may be misleading in this respect. The Models have been designed with this lack of available data in mind. Over-all data requirements are based on that premise that an observer will be used to collect most of the information required.

IV. The Use of the Model in Planning and Decision Making

The availability of models which will permit the simulation of both the economy and the transport system will, for the first time, allow the planner to investigate the interaction of the two. A real question is the manner in which this set of models can be used for planning. This problem is much too involved to be treated in detail here. We hesitate to ignore it however because it is an important area and one which has received a great deal of our attention both in its relationship with model design and for its own sake.

The model provides the planner with a rather complete and detailed set of consequences for each alternative investigated. Any number of different alternatives can be produced by manipulating the controllable variables of the model. The problem ultimately becomes one of placing values on each of these consequences and deciding between the alternatives. This is a difficult task involving both the differentiation of the incidence of benefits and the selection of the value systems to be used. And, it must be done in full awareness of the social and political constants which exist in the country. We will for the moment, therefore, leave the evaluation procedure as the subject of a future paper.

Appendix

This appendix gives a more detailed description of the internal workings of the transport sector than was provided in the main body of the paper. It is presented by a sequential description of the computational procedure.

Computational Procedure

Computation is divided into four major sectors: the supply demand disaggregation sector (SDDISG); the edit sector (EDITOR); the network flow sector (NETFLO); and the link cost sector (COSTER). See Figure 6. The disaggregation sector which begins the computations and prepares seasonal supply and demand vectors for each subcommodity. This is followed by the edit sector which performs network edit, and an initial R-factor computation. The calculation of minimum path trees, the determination of the distribution pattern, link assignment, and network file update are all done in the network flow sector. The link cost sector consists of the determination of the appropriate modal cost submodel for cost-performance calculations, the pricing policy routine, the computation of network system performance measures, network file update, vehicle availability and requirements determination and transport summary. All operations are shown in greater detail in Figure 7.

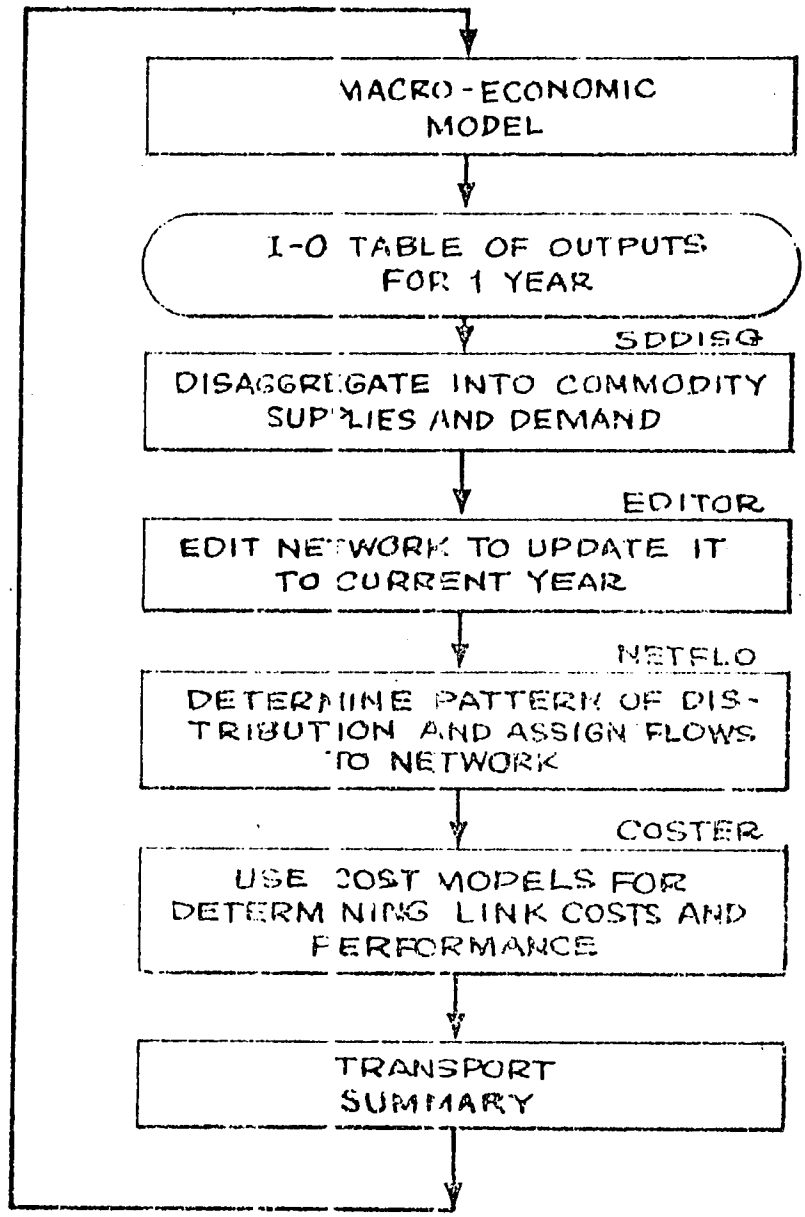
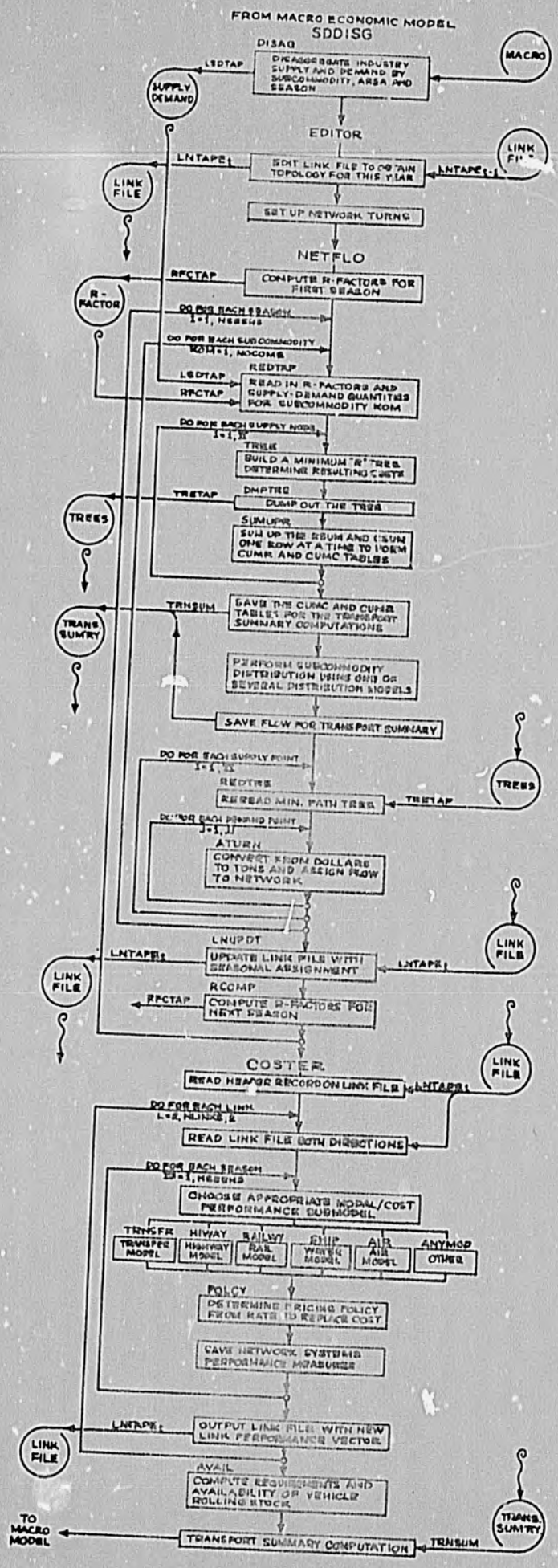


FIGURE 6 TRANSPORT MODEL SHOWING ITS LINKAGE WITH THE MACRO-ECONOMIC MODEL.


FROM MACRO ECONOMIC MODEL
SDDISG
DISAG
DISAGGREGATE INDUSTRY SUPPLY AND DEMAND BY SUBCOMMODITY, AREA AND SEASON
MACRO
LSDTAP
SUPPLY DEMAND
EDITOR
SPIT LINK FILE TO OBTAIN TOPOLOGY FOR THIS YEAR
LNTAPE1
LINK FILE
SET UP NETWORK TURNS
NETFLO
RFCTAP
COMPUTE R-FACTORS FOR FIRST SEASON
R-FACTOR
DO FOR EACH SEASON
DO FOR EACH SUBCOMMODITY
REDTAP
READ IN R-FACTORS AND SUPPLY-DEMAND QUANTITIES FOR SUBCOMMODITY KOM
DO FOR EACH SUPPLY NODE
TREE
BUILD A MINIMUM "R" TREE DETERMINE RESULTING COSTS
DMPTRE
DUMP OUT THE TREE
TREES
TRETAP
SUMUPR
SUM UP THE RSUM AND CSUM ONE ROW AT A TIME TO FORM CUMR AND CUMC TABLES
TRANSUM
SAVE THE CUMC AND CUMR TABLES FOR THE TRANSPORT SUMMARY COMPUTATIONS
TRANS. SUMRY
PERFORM SUBCOMMODITY DISTRIBUTION USING ONE OR SEVERAL DISTRIBUTION MODELS
SAVE FLOW FOR TRANSPORT SUMMARY
DO FOR EACH SUPPLY POINT
REDTRE
REREAD MIN. PATH TREE
DO FOR EACH DEMAND POINT
ATURN
CONVERT FROM DOLLARS TO TONS AND ASSIGN FLOW TO NETWORK
LNUPDT
UPDATE LINK FILE WITH SEASONAL ASSIGNMENT
LNTAPE2
RCOMP
COMPUTE R-FACTORS FOR NEXT SEASON
COSTER
READ HEADER RECORD ON LINK FILE
DO FOR EACH LINK
READ LINK FILE BOTH DIRECTIONS
DO FOR EACH SEASON
CHOOSE APPROPRIATE MODAL/COST PERFORMANCE SUBMODEL
TRNSFR
HIWAY
RAILWY
SHIP
AIR
ANYMOD
TRANSFER MODEL
HIGHWAY MODEL
RAIL MODEL
WATER MODEL
AIR MODEL
OTHER
POLCY
DETERMINE PRICING POLICY FROM RATE TO REPLACE COST
SAVE NETWORK SYSTEMS PERFORMANCE MEASURES
OUTPUT LINK FILE WITH NEW LINK PERFORMANCE VECTOR
AVAIL
COMPUTE REQUIREMENTS AND AVAILABILITY OF VEHICLE ROLLING STOCK
TO MACRO MODEL
TRANSPORT SUMMARY COMPUTATION

A. Supply Demand Disaggregation

Computations begin with the disaggregation of the regional supplies and demands for each industry into regional, seasonal, subcommodity, supplies and demands. Unit production costs for each subcommodity are also supplied. Input to this computation consists essentially of the supply and demand information from the macro-economic data, as well as the disaggregation factor table. Outputs are stored in a supply and demand file known as the LSDTAP in the order in which they will be used later in the distribution process.

B. Network Edit

Editing of the Network Link File takes place next. By means of an edit routine, links can be introduced, deleted, or changed. Entirely new Network Link Files can also be created. Input to the edit routine is from one of two sources, either the Network Link File (LNTAPE, which contains the edited network from a previous time period--if there was one) or alternatively from the system input, which contains in card image form the new links to be added, changed, or deleted. This is referred to as the Edit File. Links are added to the network by merely placing them in the Edit File for the year in which the change is desired. Links are

deleted by prefixing Edit File input cards with a minus sign.

The edit process is carried out by reading each link of last year's Link File in turn. For each it checks to see that this link is not in the Edit File. If it is, it then takes the appropriate action, either changing it or deleting it from the new Link File. When all the links in last year's Link File have been read, the routine checks to see if there are links in the Edit File which should be added to the Link File. If so, it adds them. Output from the process takes place onto a new Link File, known as LNEW, which contains this year's network. Once the process is finished, the files are switched and LNTAPE becomes LNEW.

C. R-Factor Computation

The R-factor computation for the first season is now done. During the edit process, the vector of Link Performance Characteristic for each link was saved in memory. The R-factor computation is now merely the multiplication of these Link Performance Characteristics by the appropriate Commodity Preference Vector for each subcommodity in turn. The R-factors are saved on RFCTAP. At this point in the computation, therefore, there are three files outstanding--the network link file, LNTAPE; the supply and demand file, LSDTAP; and the R-factor file, RFCTAPE.

D. Network Flow

The computations now enter an iterative phase, as shown on Figure 7, in which the computations are repeated for each season and for each subcommodity. Initially, season one and subcommodity one are worked with. The LSDTAP is now read and subcommodity supplies, demands, and regional unit production costs for the first subcommodity are stored in the primary memory along with lists of the supply and demand nodes. Next, the set of R-factors for the subcommodity under consideration is obtained from RFCTAP.

E. Minimum Path Computation

The minimum path tree program is now called and a tree is built for each node which supplies this subcommodity. The first tree is from the first supply node to all other nodes. The path found is that which gives the minimum sum of R-factors from supply node to demand node. The consequential cumulative C's are also computed. The cumulative C's are the out-of-pocket costs to go from each supply node to each demand node, along the minimum R path. Once the tree is built for a single supply node, the tree is scanned and rows respectively of the cumulative R table and the cumulative C tables are developed. This process

is then repeated for each node which supplies this particular subcommodity. The process is completed when all supply nodes for the subcommodity under consideration have been treated. The cumulative R and cumulative C tables which have been developed in memory are now complete. They are dumped out for use later during the summary process.

F. Distribution of Flows

Once the CUMR and CUMC tables have been developed in memory, a distribution model can be used to determine the flows between each of the supply nodes and each of the demand nodes. As it presently stands, one of two distribution models may be used, DISTR1 or DISTR2. DISTR1 is an inverse impedance model which destributes the flow according to weightings assigned to each point. Weights for each point are computed by taking the inverse of the cumulative R-factor for the point taken to an empirically determined power. Alernatively, the linear programming transportation formulation (DISTR2) can be used to do the distribution. DISTR2 works particularly well in cases where the flow is of a single homogenous product. For non-homogenous or very mixed products, DISTR1 is more suitable. The computational result of either distribution procedure is a

table called FLOW which gives the quantity interchanged between each of the supply nodes and each of the demand nodes. For the distribution procedure of DISTR1, one should expect that the flow matrix would contain largely non-zero entries. For the linear programming distribution model only M+N-1 of the entries will be full, where N refers to the number of supply nodes and M the number of demand nodes.

G. Assign Network Flows

Flow is at this point in dollars. Before it is transformed into tons per day, it is saved along with the CUMRs and CUMCs on the TRNSUM file. This flow data will be used in the transportation summary block. Once it is converted to tons per day, FLOW is assigned over the minimum paths determined previously. This is done by the assignment routine which assigns flows to the appropriate subcommodity class, as determined by the subcommodity input form. Classes correspond to the designations, bulk, general, special, common passenger carrier, and private passenger carrier. The decision as to which class a specific subcommodity belongs is left up to the user.

The table into which flows are being assigned is fairly

extensive since it contains an entry for every class of flow over every link, as well as an entry for every turn. This makes a total of 20 entries for each link addition to the entries describing the topology of the network. Flow assignments are allowed to build up over all commodity classes. Entries into this table, therefore, continue to grow from the beginning of the assignment for a particular season to the end of it.

The computations are now repeated for each subcommodity assigned to the network. For each subcommodity a new set of R-factors and a new set of supplies and demands are read, using the LSDTAP and the RFCTAP files.

H. Link Update

Once the assignment of all subcommodities for a season is completed, the information in the volume table is transferred to the Link File. The flows on the assignment table are in tons per day. These flows are transferred to the LNTAPE and are at the same time converted into volumes of vehicles per day. This conversion from flow in tons by class to vehicles by class is made using the payload table which gives the payload for each vehicle by class. It is assumed here that the payload of each vehicle is the

average full load for that vehicle class.

Before the same network distribution and assignment computations are done for the next season, a new set of R-factor computations must be made. This produces a new RFCTAP which is used in conjunction with the old LSDTAP. The computations are now repeated for each season. At the completion of the entire assignment the routine has produced the vehicular volumes and tonnages for each class of vehicle over all of the seasons. The Link File at this stage contains not only the network topology and link characteristics with which computations were initiated, but now also contains the link utilization. The only things which remain to be done are to determine the cost-performance characteristics of each link by class and to update link performance. These are done next.

I. Cost-Performance Calculations

The link cost sector begins with the reading of the Link File. At this stage, LNTAPE is completed except that it does not contain the Link Performance Vectors. It is assumed in working with LNTAPE that the links in opposite directions are filed adjacent to each other. This is

necessary because the cost models in several classes assume that the links are interdependent in opposite directions and must have the data from both links simultaneously.

The reading of the Link File is, consequently, carried out two links at a time. The information for each direction is stored in separately-labeled files, Link 1 and Link 2. The appropriate model for predicting cost-performance on the link can now be selected. This is done by using the left-most digit of the two-digit mode number. The proper modal cost-performance submodel is now summoned. Each of the cost models assumes that there will be two basic vectors of information as input, the Link Characteristic Vector and the Link Utilization Vector. It then responds by computing the third basic vector of information, the Link Performance Vector, and returning it to the Main program. The Link Characteristic Vector contains a description of the physical and operating policies of that particular link, while the Link Utilization Vector furnishes the quantities of flow in terms of both vehicles and tons per day. From the latter the number of backhauled vehicles and the vehicle load factors can be determined.

J. Backhaul Computations

The backhaul computation is a simple one based on the concept that the vehicle flow in one direction is approximately equivalent to the vehicular flow in the other direction over a 24-hour day. In order to perform the computation we merely select the maximum number of vehicles in either direction for each class of vehicle. The computation is, of course, not performed in the same way for transfer links since there are actually no vehicles involved.

K. Link Performance Measures

The modal cost-performance models are designed to operate with one season's worth of information at a time. In order to get all seasons, computations are performed iteratively. The Link Performance Vector returned by the cost models contains the waiting time, the travel time, the total time standard deviation, the probability of loss, and the cost of travel over the link for each season. The cost of travel over the link is the cost required to furnish the service. It should be closely equivalent to the cost incurred by the fleet owner or railroad to actually provide service from one end of the link to tha other.

This cost may not, however, be the cost to the purchaser of transport, unless, of course, the shipper is also the owner of the vehicle. The price which the shipper actually pays is dependent upon the pricing policy in effect at that moment.

L. Pricing Policy

A range of possible pricing policies is taken into account by the use of a pricing policy subroutine. The "cost" determined by the cost performance model is now given to the pricing policy subroutine. The subroutine returns with an appropriate "price" substituted for the cost previously given to it. The pricing policy subroutine works in the following way. A two-dimensional rate table is supplied, indexed by mode and by class respectively. Mode is given by the two digit mode number described previously. The first digit of this two-digit code represents the actual mode (rail, highway, transfer, etc.). The second digit represents the subsystem to which it belongs. A different pricing policy can be specified for each subsystem.

The rate table contains the charge per ton mile for goods transported over this mode. No distinction is made

Previous Page Blank

for different commodities. If there is an entry given in the table for the mode and class under consideration, then this rate is used as the particular pricing policy in effect. If the table contains a zero, then the pricing policy used is a multiplier times the cost of providing the service. The price that is returned to the main program is, therefore, one of these two figures, either the rate times distance, or the cost times a multiplier which includes profit.

M. System Performance Measures

Measures of system performance are computed by summing the component inputs from each link in the network. This is easily done as we proceed link by link. Summations are maintained for waiting times, travel times, transfer and terminal times, as well as costs, revenues, vehicle miles and ton-miles for each subsystem by class and by season.

Once all use aspects of the link performance vectors have been extracted, the new Link Performance Vector is prepared by merging the performance vector with "price" inserted for "cost" back into the Link File. The whole simulation and pricing operation is now repeated for each season after which new LNTAPE records are written for the two links in opposite directions dealt with by the cost-performance model. These computations are repeated for

each set of two links in the Link File.

N. Vehicle Requirements and Availability

Next, a requirements-availability ratio is calculated for the vehicles in each subsystem using the network waiting time saved from the individual link calculations. Vehicle availability is found by multiplying the number of vehicles of each mode and class by the number of working hours in each mode and the total number of days in the period. Requirements are determined based on link waiting and travel times which give the number of hours which each of the vehicles is tied up in service on the network. The requirements-availability ratio is used by the transfer submodel to determine the time required to obtain empty vehicles. If availability is less than requirements, then waiting times for obtaining empty vehicles becomes excessive. This is reflected by increased waiting times at points of transfer.

O. Transport Summary

The final computation is the transport summary computation. This involves accepting information from the CUMR and CUMC tables along with the flow matrix computed for each of the subcommodities and re-aggregating them into the

same groups given in the original macro-economic data. Once re-aggregation has been performed, then transport costs to each major industry are available. This information can now be used as feedback in the determination of macro-economic data for subsequent time periods.