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MODELING STATEWIDE COMMODITY FLOWS

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March 1, 1976

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MODELING STATEWIDE COMMODITY FLOWS

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MODELING STATEWIDE COMMODITY FLOWS

INTRODUCTION

In complex, modern society, increasingly, information is power -- power to enact or attack legislation, to win legal suits, to sway masses of voters or consumers, to construct or obstruct private and public actions. The vast amount of information available and the increasing rate of increase of new information -- the information explosion -- make information overload inevitable for individuals and institutions in society. Yet, at the same time, some institutions face the problem of a gap between serious information needs and what is available.

State departments of transportation (DOTs) currently face both problems, information overload and gap. Until recently a highway department, the typical DOT is top-heavy with information about highway passenger transportation. Recent trends in government toward multi-modal consideration combined with issues and problems in commodity transport, make commodity flow information a serious need for state DOTs.

The many pressing issues in commodity transport are interrelated beyond most DOTs' abilities to deal with them. Consider: the trend in truck-rail relative market shares; the energy situation; environmental concerns; anti-highway sentiment; economic and social implications of rail abandonment; the bankruptcy and reorganization of northeast and midwest railroads; and the competition of new modes; for example coal slurry pipelines. The state DOT is forced by legislation to estimate impacts of actions both within and beyond its control

One method employed by social institutions both to order information (and thereby reduce overload) and to narrow their information gaps is modeling.

This paper will examine the modeling of commodity flows within the context of statewide multi-modal transportation planning. By modeling commodity flows, a state DOT could more effectively evaluate: the demand for truck vs. rail transport in the future; the impact of fuel prices and shortages; environmental impacts of alternate transportation policies; need for additional highway facilities; rail abandonment and subsidy strategies; and impact of new modes on other modes and the total system.

This paper will evaluate the feasibility of implementing a statewide commodity flow model and attempt to determine a modeling strategy for the state DOT to follow. After an introduction to modeling concepts and modeling's place in the planning methodology, the paper will focus on the three parts of model development: theoretical model structure, modeling techniques, and model implementation. The aim will be to summarize the accepted theory, describe the proposed techniques, and evaluate the proposals and implementations. Recommendations will suggest the appropriate course of action for a state DOT to follow to deal with its commodity transport information overload/gap problem.

It will be seen that the structure of commodity flow models is well defined and accepted. No techniques can be considered tried and true, but there are numerous possible avenues. The major difficulty lies in implementation, notably the data which simply does not exist. An effort to begin upgrading the data base but delaying full-scale modeling effort is deemed most appropriate for states.

The following section attempts to answer the question of "so what?"; i.e. it provides a framework from which the reader can evaluate the significance of modeling in making social decisions.

MODELING AND PLANNING

Like many human endeavors, the process of modeling has been refined

into a sophisticated technological tool, too complex and specific for widespread public understanding. Yet the process is a simple one, so simple a child uses it automatically when learning to speak.

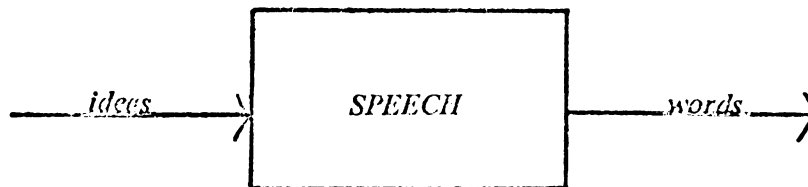


FIGURE 1: SPEECH MODEL

A model is a "representation of a real world system that behaves like the real world system in certain respects".¹ With speech, a child models his/her idea system, utilizing a limited vocabulary to produce a system of words which hopefully means what she/he is thinking. The better the child's speech model, the more her/his words "behave" like her/his ideas.

Systems science, the field of human endeavor which studies models, requires that models be abstract representations of reality.² Thus, in systems science terminology, speech is really a system; Figure 1 is the model, since it abstractly represents the speech process. The most basic model of the modeling process, shown in Figure 2, consists of three basic parts: input, the system model, and output. Complex social decision-making models are typically a collection of interrelated computer programs. The

¹Thomas J. Manetsch and Gerald L. Park, System Analysis and Simulation with Applications to Economic and Social Systems (East Lansing, Michigan, Michigan State University, 1974), p. 11.

²Ibid.

input is information and accepted projections of social indicators. The system model programs perform calculations, using that information and equations based on the system's observed real world behavior. The output is projections which purport to resemble the real world system's response to hypothetical input conditions.

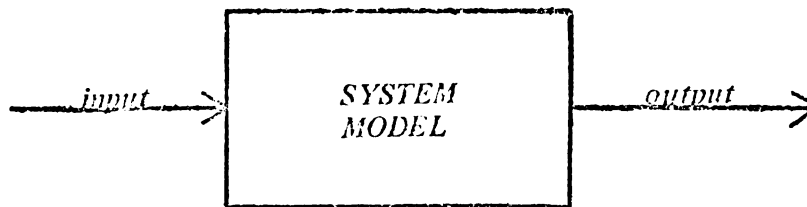


FIGURE 2: A GENERALIZED MODEL

Models have proven extremely useful to society as part of a problem solving methodology which attempts to accurately simulate a portion of the world in order to determine the effects and effectiveness of alternate strategies of social action. The methodology has enjoyed greatest success where:

- (1) the aims or goals of the system are well defined and recognizable, if not quantifiable;
- (2) the decision-making process in the real system is centralized or fairly authoritarian; and
- (3) a long-range planning horizon is possible.³

Modeling of transportation systems, as with other complex social systems which fail the first two tests, has predictably enjoyed mixed success.

³Ibid., pp. 6-7.

Problems and failures notwithstanding, the technique has become a cornerstone of the current passenger transportation planning process, beginning with the Chicago and Detroit studies of the 1950's.⁴ The typical transportation model, illustrated in Figure 3, relates socio-economic information to travel information for a base year and, given projections of socio-economic information for a horizon year, the model projects travel information for that horizon year. Alternate transportation systems are simulated by the

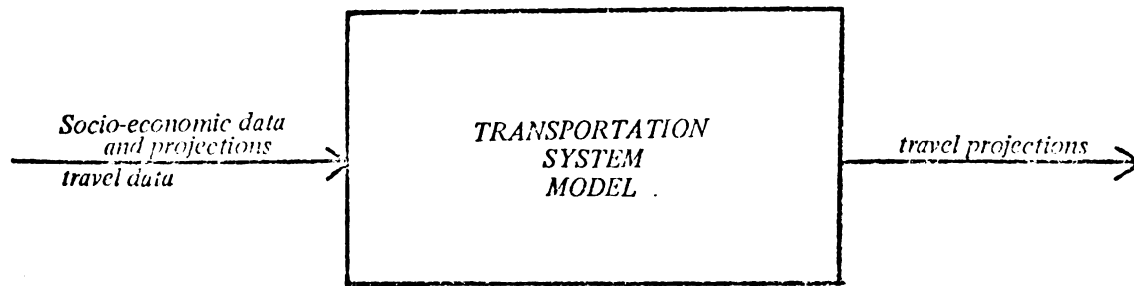


FIGURE 3: A GENERALIZED TRANSPORTATION MODEL

system, and the resulting different travel projections are evaluated by planners in an effort to choose the "best" transportation system.

The deficiencies of modeling in planning are freely admitted by those who create and/or use models. Models aid the rational aspect of the planning process but humanistic, non-rational concerns are often equally or more

⁴B.G. Hutchinson, Principles of Urban Transport Systems Planning (New York, McGraw-Hill Book Co., 1974), p.1.

important than the rational concerns; the planning process thus seldom bases decisions predominantly on model output.

A model necessarily introduces uncertainty as to the reliability of its forecasts. The future is by definition also uncertain, yet planning grapples with the future lacking the power to actually shape future events. The "solution analysis" step of the transportation planning process⁵ requires forecasting future events in a quantified value-oriented form. That need is greater than the need for totally reliable forecasts (which are unavailable in any case regardless of the need for them). Since there is no evidence that social systems are so complex as to be "unmodelable", modeling is an appropriate technique for the rational aspect of planning to develop.

Some modeling efforts fail to be socially useful. The reason for failure is sometimes that the model itself inadequately resembles the processes of the real world, i.e., the theory is poorly developed, or the techniques are too weak. Other times, as will be shown to occur with statewide commodity flow models, the theory and techniques exist, but the data requirements are so massive as to preclude implementation.

THE MORPHOLOGY OF COMMODITY FLOW MODELS

In its most abstract formulation, a commodity flow model may be conceived as in Figure 4. Socio-economic and travel data define the internal parameters of the model, relative to other travel data; i.e., the model is calibrated so to "predict" existing data. After calibration, projections of future socio-economic conditions and transportation alternatives are input and the model generates travel projections for the future.

Historically, commodity flows have been studied and modeled less than

⁵Ibid., p.7.

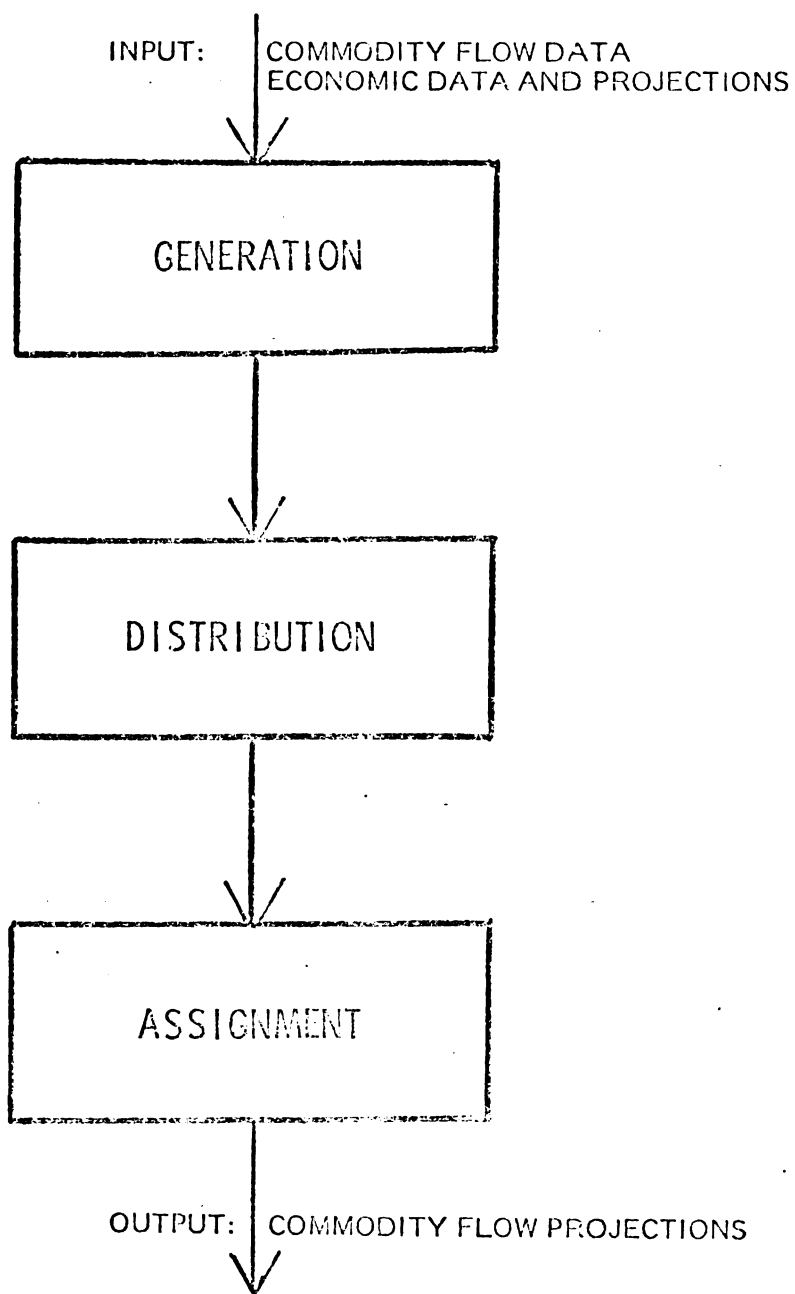


FIGURE4 A GENERALIZED COMMODITY FLOW MODEL

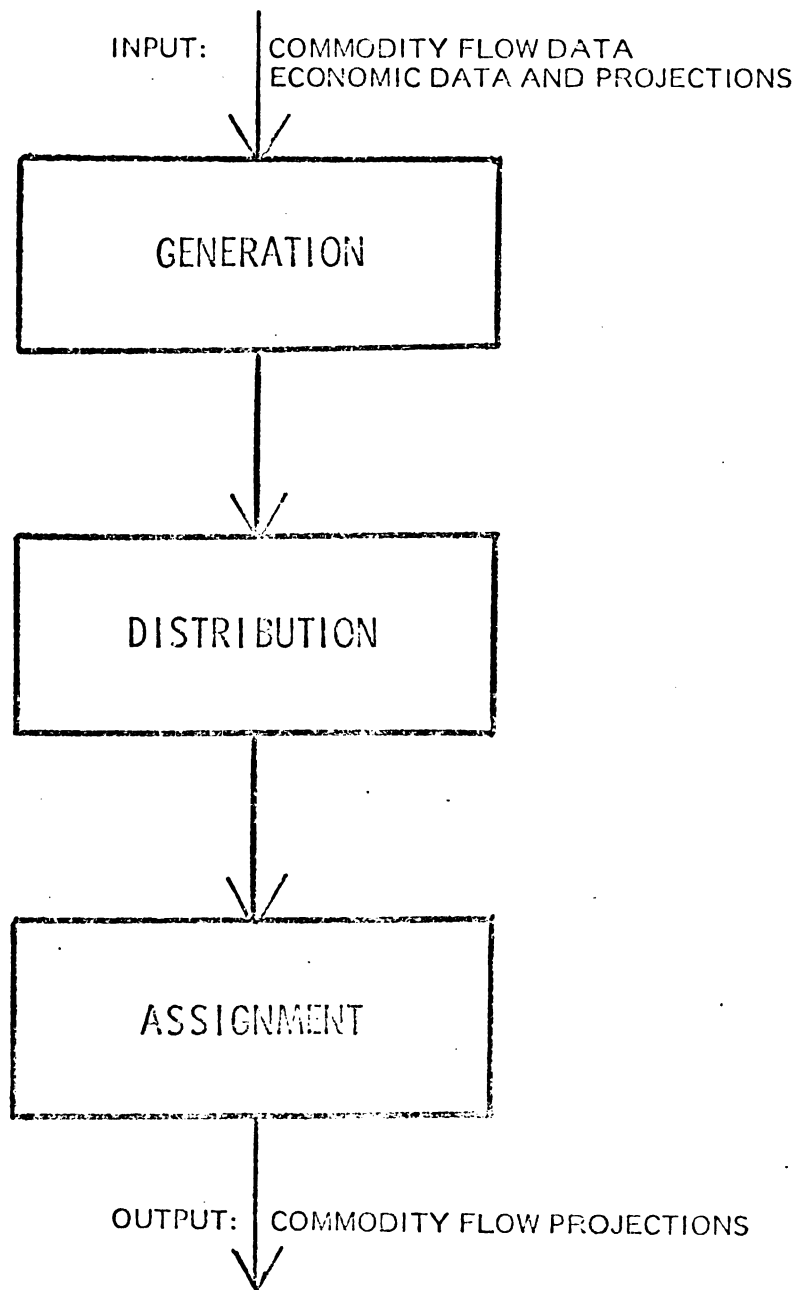


FIGURE4 A GENERALIZED COMMODITY FLOW MODEL

and later than passenger flows. The morphology of commodity flow models thus resembles the typical passenger flow model. In Figure 4, the real world processes in commodity flow are represented by three subsystems: (1) generation of goods for shipment and the demand for those goods (productions and attractions), (2) the distribution of those goods to points of consumption by various modes of transport, and (3) the assignment of commodity shipments to specific routes on the transport network. (The generation and distribution phases are sometimes together referred to as the "demand" for freight transportation.) Each of the subsystems is itself a system model and may be characterized in terms of input, system model, and output.

The generation subsystem receives the model's initial input of socio-economic data. Utilizing economic relationships, the model outputs a measure of the commodities produced in and attracted to each distinct zone or region of the area under study. As such, it is an econometric model, but for transportation planning, it must be sensitive to changes in transportation variables to be effective.

The distribution subsystem requires as inputs those productions and attractions at each zone. It then distributes the commodities produced among zones of attraction, deriving matrices of the quantities of goods which move in both directions on all modes between all possible pairs of zones. Often the distribution process is subdivided into geographical distribution and modal split phases. The former distributes commodities between production and attraction zones. The latter assigns commodity flows to transport modes. Since the two phases are quite different, they will generally be discussed separately here.

The modal zone-to-zone commodity flow matrices are the inputs to the network assignment subsystem, which outputs traffic assignments to all specific routes within each modal network. An impact battery ordinarily

then translates the projections of commodity flow traffic into value-oriented indicators. The commodity flow assignment subsystem is not essentially different from that for passenger flows.

The subsystems which are appreciably different for commodities versus passengers are the generation and distribution subsystems, i.e., the "demand" for freight transportation. This paper will therefore focus on the demand forecasting problem.

Thus far implicit to this discussion have been some important prerequisites to a transportation modeling effort: the modeling base. The demand phase requires disaggregation of the study area into a system of contiguous, somewhat homogeneous data zones and a transportation network must be tied into the zone system. Graphic examples of zones and networks are shown in Figures 5 and 6.

The network can represent transport modes explicitly, but recent studies have favored the "abstract mode" approach wherein a mode is implicitly defined by a vector of characteristics, e.g., time and cost of using the mode. The abstract mode approach has the advantage of separating related modes having very different service characteristics (e.g., regular and piggyback rail) and of providing the opportunity to define a non-existent mode for experimentation purposes.⁶

Similarly, commodities may be grouped explicitly or abstractly.⁷ An

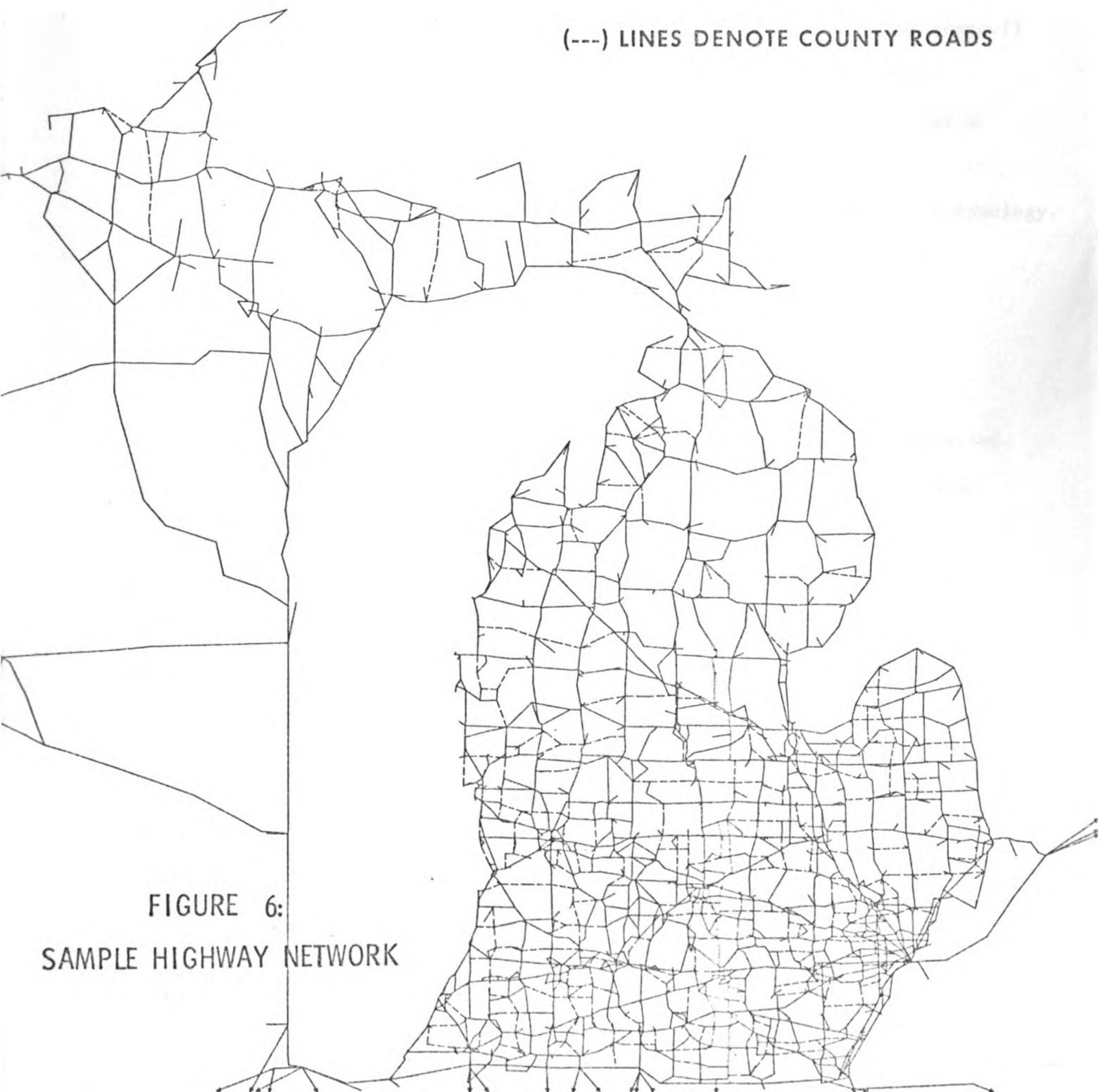
⁶M. S. Bronzini, et al, "A Transportation-Sensitive Model of A Regional Economy", Transportation Research, Vol. 8, p. 50.

⁷H. D. Vinod, Forecasting the Freight Demand by Stages (Studies on the Demand for Freight Transportation), Vol. 11, Princeton, New Jersey, Mathematic, Inc., 1969), pp. 319-320.



MICHIGAN'S STATEWIDE TRANSPORTATION MODELING SYSTEM

1970 HIGHWAY NETWORK



extreme example of the latter is the Department of Transportation Office of Systems Analysis breakdown of all commodities in three classes characterized by high, medium, and low dollar value.⁸

A major factor in the usefulness of a model is its level of aggregation. The most sophisticated models are "micro-models", that is, they process information at fine levels of aggregation. The availability (or lack thereof) of disaggregated primary data and the problems of the size of computer programs required to process it often force systems designers to opt for a "macro-model", used in conjunction with a "disaggregation model".⁹

The subsystems of a commodity flow model form a neat theoretical morphology. The next stage toward implementation is finding concrete techniques to represent the subsystems mathematically.

TECHNIQUES

This section demonstrates what empirical techniques have been suggested to model the demand subsystems. It is the techniques which determine what data and level of detail is required for successful modeling effort. As will be seen, the best techniques are theoretically straightforward, yet require too complex comprehensive data for less than a major commitment of resources.

⁸Carl N. Swerdloff, "Developing a National Model of Intercity Freight Movement in the United States", (Freight Traffic Models Symposium Proceedings, PRTC Co., Ltd., 1971), p. 110.

⁹A Model for Allocating Economic Activities into Sub-Areas in a State (New York, Alan M. Voorhees & Associates, Inc., 1966); and H. D. Vinod, "The Estimation of Tonnage Shipped Between City Pairs on the Basis of Incomplete Information" (Studies on the Demand For Freight Transportation, Vol. I) Ch. 6.

Regression Analysis

A widely used technique for modeling in general is the statistical methodology of multiple regression analysis. Regression produces a model of the purported causality of a set of independent variables on a dependent variable.

Regression has been used for the generation subsystem, both phases of the distribution subsystem, and for combinations thereof in various models. The technique requires base year data for both the independent and dependent variables, and horizon year projections for the dependent variables. It is an extremely flexible tool, but precautions must be taken against assuming causality if the variables are correlated but not causally. Proper choice of variables to consider is required to predict changes in trends.

Systems of simultaneous independent regression equations are better than ordinary regression equations in expressing causality. They are, in general, relatively expensive to develop and operate and require much more detailed data by regions than is available.¹⁰ Such systems are not widely used at present, but they are an attractive possibility for future effort.

Input-Output Analysis

The most widely respected micro-economic models use the Leontief inter-industry input-output transaction matrix. The technique requires a matrix of inter-industrial transactions and characterizes any given industrial sector's production function as a vector of "technical input coefficients".

¹⁰Vinod, Vol. 2, p. 30; and

H. W. Bruck, et al, A Methodological Approach to Commodity Flow Analysis in the State of California, Draft Final Report (Urban Systems Laboratory, Massachusetts Institute of Technology, 1974), pp. 43-50.

Using as its socio-economic input the household demand for all goods and services, the model determines the goods and services produced due to all levels of demand.

The input-output model serves as the generation and geographic distribution subsystems in the more noted commodity flow models. The detailed data on inter-industrial transactions required for input-output analysis is a serious impediment to its wider use. Figure 7 is an illustration of the required input-output data matrix. The fact that such data is expensive to collect and the model requires considerable effort has resulted in only two successful implementations, the Brookings model and the Northeast Corridor Project.¹¹

Gravity Model

The gravity model is a widely used distribution model from the urban passenger transportation planning process. Its basic premise is that the magnitude of goods produced in one zone and attracted to another is directly proportional to total productions in the first and total attractions in the other and is inversely proportional to a measure of the zones' spatial separation. Some early commodity distribution models were the gravity type. The gravity model utilizes the production and attraction projections from the generation subsystem, and requires flow data for calibration. The model is advantageous for highly-aggregated heterogeneous commodity classes, but

¹¹Methodological Framework for Comprehensive Transportation Planning, Final Report (Pennsylvania Transportation and Traffic Safety Center, Pennsylvania State University and Transportation Research Institute, Carnegie-Mellon University), p. 119.

From \ To	Industry 1 at Node	Industry j at Node	Industry n at Node	Total
	1 m	h	1 m	
Industry 1 at node 1				
2				
.				
.				
.				
m				
S. Total				
Industry 2 at node 1				
2				
.				
.				
.				
m				
S. Total				
Industry i at node g		x_{igjh}		x_{igoo}
Industry n at node 1				
2				
.				
.				
.				
m				
S. Total				

FIGURE 7: A GENERALIZED INPUT-OUTPUT TABLE

for a finer micro-model, it sacrifices precision. It usually requires "validation of its parameter estimates by (an independent) measure of best fit."¹² The model is a heuristically derived passenger distribution model, and recent commodity flow modeling efforts have turned to the more theoretically economic linear programming approach.

Linear Programming

The technique of linear programming is an econometric tool which minimizes or maximizes an expression subject to a series of constraints. The linear programming model as applied to commodity flows seeks to minimize the overall cost of shipping a commodity from several production points to several consumption points.

Linear programming was used, at least for some commodity classes, in all three of the best known commodity flow modeling efforts. The technique requires data on commodity flows and on freight rates by mode and by commodity class. Programming works best for homogeneous commodity classes and zones; for heterogeneous commodity classes, the gravity model is superior. However, for follow-up to sophisticated micro-economic generation subsystems (such as input-output analysis) programming is preferred.¹³

IMPLEMENTATION

The techniques of all aspects of commodity flow modeling have one thing in common: requirements for much detailed data--data which does not exist and for most states is not being collected. Before specifying exactly what

¹²David T. Kresge and Paul O. Roberts, Systems Analysis and Simulation Models (Techniques of Transport Planning, ed. by John R. Meyer, Washington, D. C., The Brookings Institution, 1971), p. 53.

¹³ibid.

data is needed, it would be enlightening to review attempts to actually implement commodity flow models.

The significant attempts have occurred in two groups: (1) models which have been successfully implemented, usually a national or multi-state model, for which detailed economic and transportation data are already collected, and (2) models which have been proposed yet not implemented, usually statewide models.

National or Multi-state Models

The Brookings Institution model is a model for economic and transportation planning developed at Harvard University and implemented in Columbia at a cost of \$0.5 million. The model uses explicit separate modes and commodity classes. The generation subsystem uses input-output analysis. Commodities are geographically distributed by the gravity model or linear programming, depending on commodity characteristics. Modal split is accomplished by minimum cost assignment. The Brookings model was the first to implement an input-output model in a transportation framework.

O'Sullivan and Ralston have compared the results of different distribution models in U.S. and British cities for which the government collects commodity origin-destination data.

The Northeast Corridor Transportation Project implemented a collection of models to simulate commodity flows within the Northeast Corridor and between Northeast cities and the remaining of the SMSA's on which the census gathers commodity flow data. The model performed generation, distribution, and modal split together, utilizing regression analysis supplemented by linear programming. A landmark effort, the project has served as a starting point for the states considering implementation of a commodity flow model.

Statewide Models

The Connecticut Goods Movement Projection and Distribution Model is the only statewide commodity flow model to be implemented. The model is actually two models, one for each of the explicit modes, truck and rail. Both generation models are regression. The truck distribution model is a gravity model. The rail distribution model uses average growth factors, a passenger transportation technique similar to but simpler than the gravity model. The Connecticut model suffers from its simplicity. Costing \$1 million and requiring 3 years effort, it is an adaptation of the Bureau of Public Road's Urban Transportation Planning Modeling process and uses only existing data sources. The model unfortunately did not perform well as a commodity flow model and is not presently used for planning.

Pennsylvania's Methodological Framework for Comprehensive Transportation Planning proposed the most sophisticated statewide commodity (and passenger) model to date. The model uses the input-output technique to generate and distribute commodities. The modal split phase uses abstract modes and commodities in constrained regression. Thoroughly researched and carefully detailed, the model framework has several advantages over Connecticut's: (1) it models transport demand directly, with the theoretically superior input-output technique; (2) it is truly multi-modal in the distribution and assignment subsystems; and (3) the model is sensitive to changes in the transportation network through a price model. Projected to cost \$7.2 million and require 5 years in development, the Pennsylvania model has not been implemented for statewide use. It has been tested on a "completely artificial" network with 4 nodes, 9 commodity types, and 2 modes. It functioned well, but the experimenters still consider it "premature to base policy decision

strictly on (it)."¹⁴ Nonetheless, it is the most current complete study of commodity flow modeling.

The California Transportation Model was the first statewide transportation model which proposed an input-output econometric model for its generation subsystem. The distribution subsystem was to be a gravity model. The entire system was estimated to cost \$6 to \$9 million and to require 4½ years effort. The study design was not very substantive, however, and the model has not been implemented. In its Methodological Approach to Commodity Flow Analysis, California outlines four potential approaches:

- (1) to ignore (commodity flows),
- (2) to develop new forms of models, which would be tested with existing data,
- (3) to develop more systematic sources of data with which existing models could be tested, or
- (4) to develop some combination of options (2) and (3).

The study concludes that "option (3) appears to be the most practical approach for planning agencies to pursue, given limited budgets."¹⁵

The Problem Summarized and a Recommendation

The Connecticut model serves as an important lesson: a model which was too simple to adequately model so complex a system as a statewide commodity transport system. Relying on modified urban passenger transportation models and existing data did not suffice. Happily, techniques have been developed

¹⁴Bronzini, p. 58.

¹⁵Bruck, pp. 10-11.

specifically for commodity flow modeling. The current best effort seems to be an input-output (or alternatively simultaneous equations) technique for generation, distribution with linear programming and abstract-mode and commodity modal split.

Such models have been proposed, but not implemented on a statewide basis--the reason: the complexity and detail of data required, the lack of such data, and the high cost of its acquisition. The data required by the "current best" model includes:

- (1) travel data: origin-destination commodity flow data stratified by zone, by mode, by commodity class, in tons and dollars;
- (2) socio-economic data: population, employment by economic sector, and gross product, all stratified by zone;
- (3) commodity data: weight, bulk, value, perishability, pilferage, insurance costs; and
- (4) transport data: cost of shipment for each mode, stratified by commodity characteristic.¹⁶

Some of the socio-economic data exists at an adequate degree of disaggregation for use. The travel data is needed at a much finer disaggregation than that collected by the U.S. Bureau of the Census. (The Census of Transportation provides origin-destination data only for 25 SMSA's.) Freight rates are so complex as to be a problem whether collected and programmed explicitly or as calibration for a freight rate model.

¹⁶Vinod, Vol. 1, Ch. 5.

The states will undoubtedly have to conduct some major surveys of shippers, possibly as much and in finer detail than is presently collected for highway passenger transportation planning. The Pennsylvania study design allocated to data collection alone \$3 million and 21 months of the \$7 million and 5 years allocated to the entire project.¹⁷

The California Methodological Approach cites the desirability of developing both new forms of models and more systematic sources of data. The report states that such an ideal effort would require "an infrastructure of continuous financial support and a base of manpower resources." Lacking such support, the California report stresses developing more systematic sources of data toward which a long-range modeling capability could be developed."¹⁸ Gradual but steady enlargement of the data and manpower base seems the most appropriate state response, given budgetary constraints, and the complexity and detail of the data required for the existing methodology.

CONCLUSIONS

Events and legislation in the area of commodity transport are forcing state departments of transportation to predict the impacts of commodity transport policies. The DOTs currently lack the information/power to properly perform that social responsibility due to simultaneous information overload and gap. Research has suggested that commodity flow models be developed to decrease the overload and bridge the gap. The theoretical morphology and concrete techniques have been adequately outlined in the literature.

The obstacle to commodity flow model implementation has been lack of

¹⁷Methodological Framework (Pa.), p. 431.

¹⁸Bruck, pp. 10-11.

the data required by all the suggested models. The data gap is so large, that a comprehensive commodity flow modeling effort at this time appears more than any state would or should attempt. A more feasible appropriate response seems to be to begin organizing and building the data base and delay large scale modeling effort.

It is unfortunate that such action will prolong the lag between the state DOT's responsibilities and its power to perform. The strategy seems to hold nevertheless a promise for decreasing the overload of information state DOTs currently receive about commodity transport and for eventually bridging the communication gap to support commodity flow modeling effort.

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