Multimodal Investment Analysis Methodology

Phase One: The Conceptual Model

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INTRODUCTION

The Intermodal Surface Transportation Act of 1991

Passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 marked the beginning of a new era for transportation policy and programs in the United States. With this legislation the federal government's almost singular focus over three decades on development of the Interstate Highway System was brought to a close. In its place the legislation redirected national transportation policy toward total system integration and intermodalism.

As stated in the Act's declaration of policy, the programs incorporated in the legislation are intended to promote a National Intermodal Transportation System consisting of "all forms of transportation in a unified, interconnected manner, including transportation systems of the future (1, Section 2). In addition, the legislation promotes the more efficient use of energy, reduced air pollution, and the increased competitiveness of United States businesses in world markets. Other departures from past policy include:

- an increased emphasis on system preservation
- a greater reliance on the private sector to fund infrastructure investment needs
- an increased flexibility for state and metropolitan area governments to allocate program funds between highway and transit programs
- an increased emphasis on freight system planning
- a closer coordination of transportation planning activities between state and metropolitan area governments
- a heightened recognition of the impact of transportation on the natural and man-made environments

Given the new direction in national policy, the legislation required or recommended a number of significant research and planning initiatives. At the national level, Title V of the Act required establishment of an Office of Intermodalism in the U.S. Department of Transportation and the creation of a National Commission on Intermodal Transportation. Both of these provisions represent a commitment on the part of Congress to move national transportation policy from a modal to a system-wide focus.

The Commission issued its final report in September 1994. In the report the Commission made twelve recommendations. These recommendations were grouped into three major categories: (1) making efficient intermodal transportation the goal of federal transportation policy, (2) increasing investment in intermodal transportation, and (3) restructuring government institutions to improve support for intermodal transportation. The twelve recommendations are summarized in Figure 1 (2).

The charge given the Commission on Intermodal Transportation further emphasizes this new policy direction. Table 1 shows the eight issues the Commission was directed to study.

TABLE 1 Commission on Intermodal Transportation Issues

1. The potential benefits to be derived from the international standardization of intermodal transportation technology
2. The current and projected market for intermodal transportation and the impact of related
3. Legal impediments to efficient intermodal transportation and the relationship between traffic flows on infrastructure investment needs,current regulatory schemes for individual modes of transportation and intermodal transportation efficiency
4. Impediments to the efficient financing of intermodal transportation improvements
5. The potential use of new technologies to improve the efficiency of intermodal transportation
6. Documentation problems associated with the transfer of freight involved in intermodal transportation
7. Areas related to intermodal transportation requiring additional research subsequent to the work of the Commission
8. The relationship of intermodal transportation to transportation rates, transportation costs, and economic productivity (1, Section 5005).

In addition to redirecting transportation policy and programs at the federal level, ISTEA encouraged state and metropolitan area governments to adopt similar changes. To insure that states moved in the desired direction the legislation required them to establish and implement six management systems and to develop new long-range transportation plans. (The six management systems required by ISTEA covered pavements, bridges, highway safety, traffic congestion, public transit, and intermodal transportation. Although required by ISTEA, these management systems were later made optional by the National Highway System Designation Act of 1995.) Both of these requirements included specific provisions emphasizing intermodal transportation and a system-wide perspective (1, Sec 1025, 1034).

The movement by states to embrace the spirit of ISTEA has not been without opposition or impediment. Traditional highway interest groups have objected to the diversion of funds to purposes other than road construction and maintenance. Also, many state departments of transportation and metropolitan area planning organizations have had a problem implementing the concept of intermodalism. This can be attributed to a lack of adequately trained staff and planning models that do not accommodate or support the type of integrated, system-wide planning envisioned by ISTEA. Even more fundamentally, transportation planners have had a problem agreeing on what types of issues and problems intermodal transportation plans should address, and how traditional transportation planning models and procedures should be modified to support a planning program that embraces all modes of transportation in an integrated manner.

To determine the extent to which states have implemented the planning requirements included in ISTEA, the Iowa Department of Transportation surveyed all fifty states. Questions asked in the survey covered the extent to which each state has implemented the six management systems, the modes of transportation included in state transportation plans, the types of modeling tools used to prepare state plans, the modal coverage of models used, and staff training needs identified in response to ISTEA. The results of this survey are presented in Appendix A.

Multimodal Transportation Planning

In an attempt to help state and metropolitan area planners respond effectively to ISTEA's emphasis on intermodal transportation and system-wide planning, the Transportation Research Board sponsored a conference in Irvine, California, in December 1992. The objectives of this conference were to:

1. Review the evolution of the planning and funding of the U.S. transportation system
2. Identify the new planning mechanisms developed in ISTEA that mandate transportation improvement programs and intermodal transportation management systems
3. Identify issues that need to be addressed in order to achieve more economically and environmentally efficient transportation systems through the optimum combined use of various modes
4. Assess how these issues need to be integrated into the planning process (3, v).

One of the key issues addressed at the conference was development of a consensus on how the scope of transportation planning needed to be modified and expanded to fully embrace the spirit of ISTEA. The conventional definition of intermodal transportation (i.e., transportation involving two or more modes to provide service for a single passenger trip or freight shipment) was felt to be too limited. As such, intermodal transportation planning typically focuses on modal interchange points and access to and from these points. The emphasis in ISTEA on system-wide transportation planning incorporates the concept of intermodalism, but its additional goals pertaining to international competitiveness, traffic congestion, air pollution, safety, and productivity transcend this concept. Consequently, conference participants adopted the concept of multimodal planning as a more comprehensive alternative. This alternative approach to transportation planning was defined to incorporate the following features:

- the description of transportation problems in non-mode-specific terms
- the identification of multiple modal options (both intermodal and mode specific) to solve transportation problems
- the evaluation of options in a manner that provides for an unbiased estimation of each mode's contribution to solving transportation problems (3, 23)

Conference participants also agreed that multimodal plans would have to address transportation services and infrastructure provided and managed by both the public and the private sectors. They further recognized their efforts would have to reflect the new realities of a global economy, changes in the logistics practices being adopted by businesses to enhance their competitive positions both domestically and internationally, growing environmental challenges, and fiscal constraints. To accommodate this much-expanded list of planning issues, the conference chairman, C. Michael Walton of the University of Texas, summarized the challenges offered by ISTEA as follows:

> Travel patterns, markets, and logistics are rapidly changing and, more dramatically, becoming globalized. The logistics of goods and passenger transport force new transport activities that in turn necessitate planning initiatives to meet diverse objectives. Although maximum mobility for both goods and passengers is a goal of transportation, it must now be accomplished with profound respect for the environment. Intermodal efficiency requires today's transportation professionals to infuse the planning process with state-of-the-art technical systems and to further develop systems that are compatible with and include consideration of overarching environmental and social concerns. ...Inherent in the quest for those solutions will be the need to test new planning models and to analyze how resources are applied to those solutions (3, 1-2).

The research presented in the following report represents an effort to extend transportation planning methods to better facilitate the analysis of the types of multimodal issues introduced by ISTEA.

Research Objectives and Approach

Traditional transportation planning models were designed for use in urbanized areas to address problems and service needs associated with passenger travel either by private vehicle or public transit. Only a few states have operational statewide transportation models, and those that do only include the highway portion of their surface transportation system. (See results of state transportation planning survey in Appendix A.) Also, those states that have tried to adapt urban transportation models for use in statewide planning have generally encountered problems in simulating freight movements. The reason for this problem is that the factors influencing passenger and freight transportation service demands are fundamentally different.

Passenger travel demands are typically estimated by relating travel purposes to underlying socioeconomic factors, such as household income, motor vehicle ownership, square-footage of retail shopping area, number of jobs, etc. On the other hand, freight transportation service demand typically depends on the profit maximizing objectives of firms. As a result, it is market driven. This means freight transportation service demands are subject to much more variation than are passenger service demands. Thus, whereas gravity types of models work well for distributing passenger trips among traffic zones, freight flow models generally require incorporation of some sort of mathematical optimization algorithm. Also, freight transportation service demands are typically subject to much greater seasonal and cyclical variation than are passenger service demands.

Lack of data on intercity passenger and freight flows presents another significant challenge to planners attempting to develop comprehensive, statewide transportation planning models. Acquiring the types of survey data typically gathered when developing urban models would be prohibitive for most states. Furthermore, even when data is available at the state level, it has been collected for purposes other than for transportation planning. This means substantial effort and cost would be required to convert it to a form usable to support statewide transportation modeling.

Another critical problem with conventional transportation models is they do not take into consideration the feedback effects of transportation system improvements on the economy. Although such models reflect the impact of diverted trips resulting from transportation system improvements, they generally do not consider future travel impacts resulting of system changes on the affected area's economy. Also, most existing transportation models lack the capability to identify the distribution of impacts associated with transportation system improvements on different population and business groups.

However, these challenges are not insurmountable. Advances in computer hardware and software, as well as new data gathering and analysis techniques, offer the promise of supporting the comprehensive multimodal modeling efforts needed to effectively implement the type of transportation program envisioned by the authors of ISTEA. Many of the components needed to operationalize this type of model already exist. These include regional input-output models, spatial interaction models, benefit-cost analysis, and geographic information systems.

The purpose of this project is to develop an investment analysis model that integrates the capabilities of these four types of analysis for use in evaluating interurban transportation system improvements. The project will also explore the use of new data warehousing and mining techniques to design the types of databases required for supporting such a comprehensive transportation model. The project consists of four phases. The first phase, which is documented in this report, involves development of the conceptual foundation for the model. Issues addressed in this phase include transportation demand forecasting methodologies, modal split and network assignment procedures, social welfare impact measurement and distribution, economic feedback analysis, and database requirements and structure. Phase two will involve the mathematical specification of the model, the identification of data sources, and the development of database structures. During phase three the model will be empirically tested. Finally, model algorithms and procedures will be automated and documented.

Organization of the Phase I Report

Prior research is reviewed in Chapter 1, which is composed of three major sections providing demand modeling background information for passenger transportation, transportation of freight (manufactured products and supplies), and transportation of natural resources and agricultural commodities. Material from the literature on geographic information systems makes up Chapter 2. Database models for the national and regional economies and for the transportation and logistics network are conceptualized in Chapter 3. Demand forecasting of transportation service requirements is introduced in Chapter 4, with separate sections for passenger transportation, freight transportation, and transportation of natural resources and agricultural commodities. Characteristics and capacities of the different modes, modal choices, and route assignments are discussed in Chapter 5. Chapter 6 concludes with a general discussion of the economic impacts and feedback of multimodal transportation activities and facilities.

Federal Transportation Policy Goals:

(1) Maximize safe and efficient movement of passengers and freight by incorporating individual modes into a National Intermodal Transportation System.

(2) Ensure federal policies foster development of the private sector freight intermodal system and reduce barriers to the free flow of freight, particularly at international ports and border crossings.

(3) Adopt federal policies that foster development of an intermodal passenger system incorporating urban, rural, and intercity service, including a viable intercity passenger rail network.

Intermodal Transportation Investment:

(4) Fund federal transportation infrastructure programs at authorized levels and strategically target these funds for maximum impact.

(5) Expand innovative public and private financing methods for transportation projects.

(6) Allow greater flexibility and expand eligibility in use of state and federal transportation funds for intermodal projects of public benefit.

Provide federal funding incentives for intermodal projects of national or regional significance.

(7) Expand the intermodal focus of research, education, and technology development efforts.

Restructuring of Government Institutions:

(8) Restructure the U.S. Department of Transportation to better support intermodal transportation.

(9) Streamline and expedite the transportation infrastructure planning and project delivery process.

(10) Require Department of Transportation concurrence on other federal agency actions that affect intermodal transportation.

(11) Strengthen the metropolitan planning organization process to accomplish the goals of ISTEA.

FIGURE 1 National Commission on Intermodal Transportation: Recommendations

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CHAPTER 1

HISTORICAL OVERVIEW OF TRANSPORTATION PLANNING MODEL DEVELOPMENT

INTRODUCTION

Transportation planning is undertaken at many levels starting from strategic planning to project planning and also over various geographic scales. During the last forty years urban transportation planning has undergone many changes and continues to evolve. But many of the basic notions developed in the early years still exist. The basic urban transportation planning process usually consists of the three interrelated major components: the pre-analysis phase, the technical phase and the post-analysis stage. The pre-analysis stage involves identification of problems or issues, formulation of goals and objectives, data collection and generation of alternatives. The problem definition needs to be broad enough to accommodate considerably broader set of possible solutions.

The technical phase involves mathematical descriptions of travel and travel related behavior, used to predict the consequences of each alternative transportation plan being evaluated. It consists of three major components: the land use-activity system model, the urban transportation model system and the impact prediction models. The land use-activity system models comprised of the spatial distribution of people, activities, and land use within an urban area are now integrated with transportation models to assess its impact on travel. They help predict urban activity patterns by generally using regional population and employment as input and distribute these totals spatially over a region. The Urban Transportation Model System (UTMS) consists of models commonly used to predict the flows on the links of a particular transportation network as a function of a land use activity system that generates travel. The sub-models are trip generation, trip distribution, mode choice and trip assignment. The UTMS predicts the quantity and quality in terms of travel time of flow on the links of a specified transportation network, given land use-activity system as input.

Assessment of alternative options needs estimates of a broad range of impacts. These include construction and operating costs, energy consumption, and air quality. The impact prediction models need the UTMS as inputs.

The post analysis phase starts with the output of the technical analysis, which is comprised of predictions of the impacts of alternative plans and policies. This phase involves evaluating the impacts, both economic and non-economic, of the alternatives analyzed; selecting the alternative to be analyzed; programming, budgeting and implementing the alternative chosen; and monitoring of the system performance.

HISTORICAL OVERVIEW OF MODELING

Urban and Metropolitan Area Modeling

The classical modeling approach called the Land-Use/Transportation System (LUTS) or Urban Transportation Planning Package (UTPP) in urban transportation attempts to provide the broader system view (1). It attempts to model both the estimation of demand and routing of traffic through a transportation system. This process is often modified to meet local data availability, study needs and modeling preferences. It consists of intercity passenger modeling and supply or network modeling. LUTS/UTPP can be carried out at different scales, at regional or local levels. The basic process remains the same but the level of detail and accuracy needed for traffic forecasts and network definition are different. The level of detail and the scale of analysis need to match. The basic structure of the LUTS/UTPP approach is illustrated in Figure 2.

The Classic Urban Transport Model

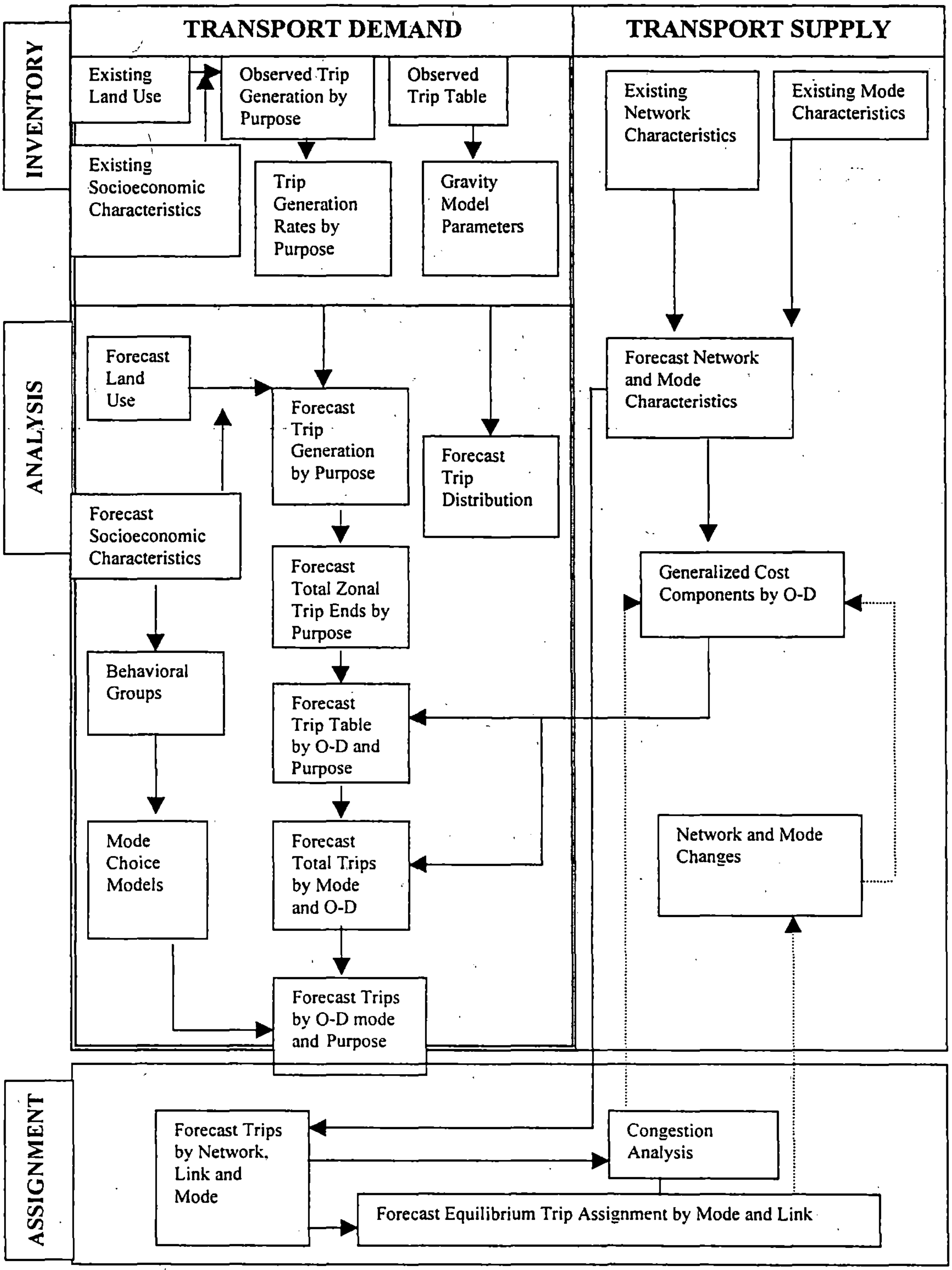
The classic transport model has been developed after years of development and experimentation. The structure of the model is based on the practice of the 1960s but has remained more or less unaltered despite the major improvements in modeling techniques since the 1970s. The approach starts by considering a zoning and network system, and the collection and coding of planning, calibration and validation data. These data would include base-year levels for population of different types in each zone of the study area as well as levels of economic activity including employment, shopping space, educational and recreational facilities. These data are then used to estimate a model of the total number of trips generated and attracted by each zone to the study area (trip generation).

The next step is the allocation of these trips to particular destinations, in other words their distribution over space, thus producing a trip matrix. The following stage normally involves modeling the choice of mode and this results in modal split, i.e. the allocation of trips in the matrix to different modes. Finally, the last stage in the classic model requires the assignment of the trips by each mode to their corresponding networks, namely, private or public transport. It is not always that travel decisions are actually taken in this type of sequence; a contemporary view is that the 'location' of each sub-model depends on the form of the utility function assumed to govern all these travel choices. This model is very narrow in its scope and does not analyze a wide range of transport problems and schemes. But it at the same time provides reference to contrasting alternative methods. It forms the basic conceptual framework for transport models (2).

During the 1940s urban transportation dealt with specific problems like congested bridge or intersection. It was very myopic in its scope. In 1944, the Bureau of Roads conducted the first "origin-destination" survey, which involved collecting data to understand the observed traffic volumes. This was the first attempt to understand the underlying traffic generating process. In the 1950s and 1960s, urban transportation studies were synonymous with regional studies. The important factor in the development of the analytical tools that formed the basis of early urban transportation planning studies was the emerging availability of digital computers capable of handling relatively large quantities of data. These computers allowed planners to analyze urban travel patterns on a region-wide basis and encouraged efforts to develop mathematical equations describing these patterns. Other factors that contributed to the growth of urban transportation planning in the 1950s include rapid urban population growth, growth in car ownership, increasing movement of population to suburban areas and increasing federal involvement in funding urban development while requiring comprehensive planning.

The Detroit Metropolitan Area Traffic Study in 1953-55 and the Chicago Area Transportation Study (CATS) in the late 1950s were pioneer studies using the emerging analytical techniques. The Detroit study employed a process that included data collection and goal formulation, development of forecasting procedures, and testing and evaluation of alternatives. Such work was matched by similar applications of "systems approaches" in other areas of economic and social inquiry and, in particular, to land-use modeling; examples were the development of spatial analysis/locational theory and the Lowry Model (1).

These studies were followed by a number of others in the late 1950s, including those in Washington DC, Baltimore, Pittsburgh, and Philadelphia. They used the computerized procedures developed during the CATS study and had the objective of forecasting future trip-making patterns and producing a long range, region-wide transportation plan. The massive data collection exercises were



Simon Lewis, Peter Cook and Marcelo Minc, "Comprehensive Transportation Models: Past, Present and Future," Transportation Quarterly, Vol. 44, No.2, April 1990, pp. 249-265.

FIGURE 2 Diagram of Typical LUTS/UTP Process

followed by lengthy analysis time on mainframe computers. Although there were adequate financial resources to gather appropriate data, computer technology was not adequate for analysis. The emphasis in these studies was on planning a highway system that would cater to the growing automobile travel in urban areas. This "systems approach" to transportation planning spread to Europe in the early 1960s and a Land-Use Transport System (LUTS) was carried out in London in the 1960s. Between 1963 and 1967, the Bureau of Public Roads published a large number of manuals dealing with the technical aspects of the planning process and the procedures developed in the 1950s and 1960s were thereby codified and institutionalized. These procedures were exclusively oriented towards analysis of long-term, capital-intensive expansions of the transportation system, mostly in the form of highways.

In 1976 federally sponsored work lead to the development of the Urban Mass Transportation Administration/Federal Highway Administration UTPS software package. UTPS was adopted by many agencies in the US and also influenced later commercial packages. This package was initially oriented to large mainframe computers, used link-coded networks with distinct modeling limitations and had limited graphics capabilities. The computational tools included capacity constrained network models, environmental impact models and stochastic equilibrium models.

In the early 1980s, the LUTS programs adapted mainframe computer program packages for microcomputer use. At the same time computer hardware improvements tried to make these complicated, multi-component systems such as the comprehensive transportation models better packaged and more user-friendly. These resulted in the adoption of menu systems, user-sensitive layering of software, graphical interfaces and database/toolbox modular approaches. This is an approach to software design that starts with, rather than ends with, the viewpoint of the user. In some cases these programs created a comprehensive CTM separated into modules with some user-oriented features, including menus and interactive modes. In other cases (e.g., Tranplan), programs were run in batch mode, normally using a dedicated database with fixed format and a separate graphics package, and, sometimes, an on-screen editor. Computational tools included disaggregated demand models for passenger transport, shipper-carrier freight models, and transportation system management models. There were also better calibration techniques.

The late 1980s saw larger and faster microcomputers with interactive menu systems and graphics communications networks with other computers. It had a toolbox and GIS approach. There was use of knowledge-based expert systems and interaction with other planning databases. This has lead to more open exchange of databases, project definition and evaluation. The tools included new network solution algorithms, demand management models and methods of combining databases to estimate origin and destination matrices and traffic generation. Their database management features included flexible format data inputs and automatic cross-indexing of network characteristics, simplified plotting commands and other user-friendly graphics-based features.

Urban and regional network analysis models have undergone more development in both theoretical basis and software packages. Features are constantly being added and improved in all packages (1).

Intercity Regional and National Models

Intercity or national transportation planning has not kept pace with the technology of urban packages. Intercity models have concentrated more towards broader policy and economic issues. Though recent developments have user friendly intercity modeling packages for policy evaluation with mapping functions but they lack the more sophisticated graphics interface available in urban CTM packages.

The first major innovation in predicting intercity passenger travel was in the Northeast Corridor of the United States in the 1960s (3). This study introduced techniques for evaluating transportation performance and also created interest in activity shift models for forecasting changes in industry location as a function of transportation changes. In the late 1960s and 1970s, a similar type of modeling was done with the Harvard-Brookings model (4). The major contribution was that it had a detailed performance and cost model of each mode and a macroeconomic model to the standard traffic assignment model, all integrated into the package along with feedback. Kresge and Roberts' basic modeling structure is still used today with improved cost-performance, modal choice and assignment. Conceptually realistic, it had massive data requirements and model calibration problems. This was evident from the applications of the Harvard-Brookings model. The integration provided in these models represented actual linkages in a more realistic manner, linking transportation with regional economic development and also linking physical parameters and operating costs. Later models have avoided this approach and have adopted a modular approach.

Very little intercity modeling was done during the 1970s other than intercity airline passenger model developed for the US and a freight-oriented model of the US Waterways transportation system (5). Both of these models were structured for mainframe computer use with limited graphics and user interaction features and relatively simple system optimizing algorithms. Many such packages were made in the late 1960s and 1970s for military logistics purposes, short term transportation studies and analysis of food aid (1).

Other than North America and Europe, the countries using CTM technology were Brazil, Argentina, Bolivia, Paraguay and Uruguay in South America, and also Egypt and Indonesia. In the 1980s, modeling developed, both theoretically and technically. Improved models considered producer-shipper-consumer interactions and the introduction of microcomputer-based models made it more accessible. Like the urban model packages, these became more user friendly and encouraged the introduction of interactive menu-driven packages and the use of database management software in the new toolbox and database approach (see Figure 3). These packages pioneered modular programs with totally independent database management function and flexibility to add software tools in a "toolbox" for modeling and evaluation purposes. They sometimes provided user-friendly basis for policy evaluation. But they lacked the sophisticated graphics interface available in urban CTM packages (1).

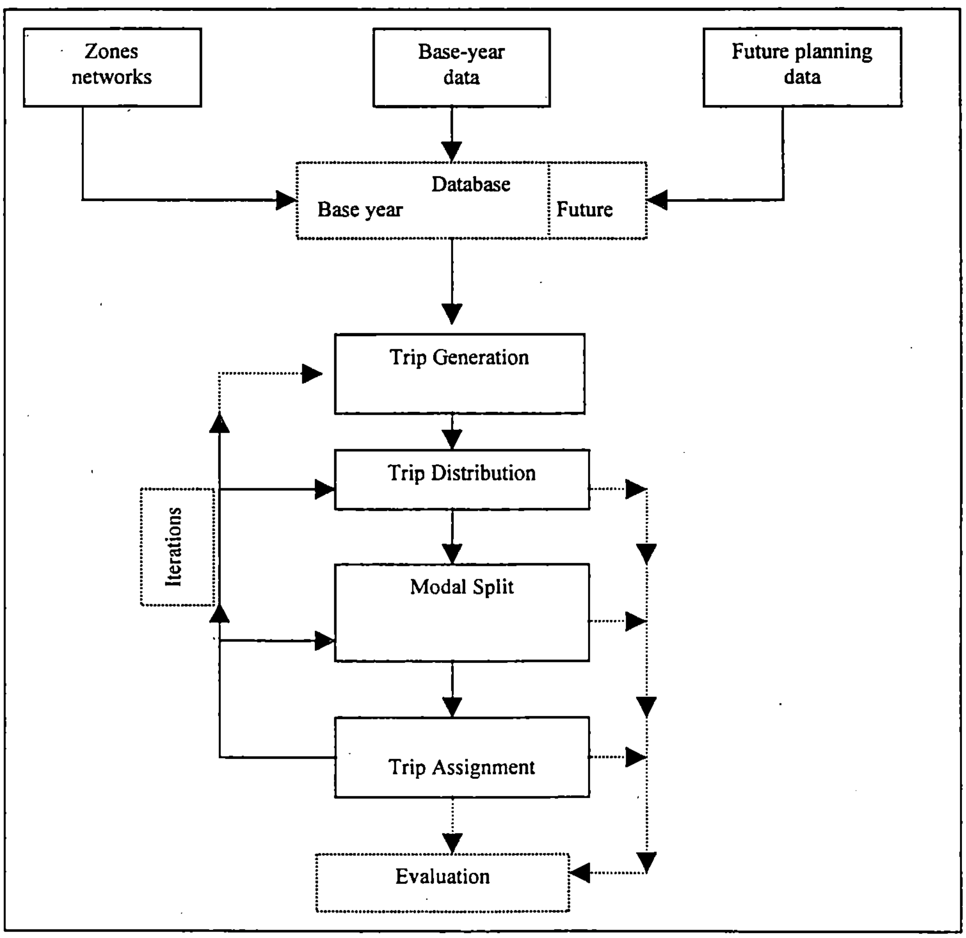
Critics of the LUTS approach note that though models have become increasingly sophisticated, their results are unreliable. Other points of concern indicate that travel behavior is not based on reliable laws and the nature of design of models for understanding a system is not, in essence, the same as required for operational planning. Moreover, there are added problems of data collecting and lack of support by institutions responsible for maintaining CTM.

In spite of all the criticisms, the CTM provides a systematic, logical framework for analysis and there are few alternative methods to CTM for system level analysis. CTM serves the purpose to get any relative values rather than absolute values for forecasting traffic. The criticisms are based on practical problems rather than theoretical ones. And many of the practical problems could be handled with the use of available technology and new technology.

THE DIFFERENT MODELING APPROACHES

Micro-economic Theories of Land-Use

These theories represent the beginning of transport and land-use modeling. The micro-economic models have common features that explain land use as a result of market mechanism, in which individual households and firms compete for space, generating an equilibrium pattern of land rent. At the same time, equilibrium prices allow for optimum allocation of land to households and firms, and these, in turn maximize their utilities. Von Thunen's model is basic for spatial economic theory and it has been extended in several ways. This model explains the effect of transport costs on the location of activities and functioning of the land market. The model has also been extended to include demand economic system works. De la Barra credited Wingo and Alonso, who incorporated the element of budget constraint in the extended version of the Von Thunen model. Christaller and Losch were cited for their explanation of the way in which multi-center regions are formed, each commodity gives rise to its own pattern of location, a network of market areas. Each pattern in turn is conditioned by others and forms hierarchies of patterns and transport networks (6).



Source: Juan de Dios Ortuzer and L G Willumsen, Modelling Transport, pp. .24

FIGURE 3 The Classic Four-stage Transport Model

Spatial Interaction Models

The first spatial interaction models were mainly based on a gravitational analogy, derived naturally from the aggregate approach. Instead of looking at individual behavior of an urban area, these models were more interested in the behavior of the different urban areas and the relationship between them. One of the pioneers in this approach was Hansen , who, using the gravitational analogy, concluded that the location of residents was a function of accessibility to employment. Then Huff interpreted the basic gravity model in economic terms and probabilities. Lowry used economic base principles and introduced a multiplier to provide a more comprehensive explanation of the urban structure. Lowry's work was then improved by Rogers and Grin using matrix methods. The original gravity formulation of the spatial interaction model was then replaced by Wilson's work on entropy maximization. This approach assumes that choices are perfectly random and then introduces a rational (cost) restriction.

Random Utility Theory and Discrete Choice Models

This is considered as a bridge between the models of microeconomic theory and spatial interaction approach. This allows integration between the theories or principles of the former and discrete aggregated formulation of the other. Discrete choice analysis uses the principle of utility maximization. A decision-maker is modeled as selecting the alternative with the highest utility among those available at the time a choice is made. An operational model consists of parameterized utility functions in terms of observable independent variables and unknown parameters, and their values are estimated from a sample of observed choices made by decision makers when confronted with a choice situation. The early applications of discrete choice models were made for the binary choice of travel mode. Some of these studies focused on the estimation of a "value of time," the trade-off between travel time and travel cost implied by a travel demand model. This value has been used to assign a monetary value to the travel timesaving in the evaluation of alternative transportation projects. Other researchers emphasized the development of policy-sensitive models for predictions of the market shares of alternative modes. Discrete modeling methods in the 1970s were oriented towards mode choice models with more than two alternatives, and applications to other travel related choices such as trip destination, trip frequency, car ownership, residential location, and housing. Studies on the choice of mode for travel to work have used different types of data from widely differing urban areas, developed more comprehensive model specifications with socioeconomic variables, and tested the forecasting accuracy of the models with data before and after transportation changes (7).

Models of Land Use Impacts on Transport

The connection between land use and transport changes cannot be ignored and long-term effects of transport policy may be of considerable potential importance. The estimation and prediction of these effects will depend on the development of reliable, quantitative models that enables two-way interaction between land use and transport. During the past decade or so a number of such models have been developed and have been used for policy testing and planning. Validation of these models is difficult because of the long time scales over which their mechanisms operate, and the Transport and Road Research Laboratory has initiated an international collaboration of seven countries to try to assess the plausibility of nine models by a comparative analysis of their structure and performance.

The International Study Group on Land-Use/Transport Interaction compared the behavior of the models when applied to a set of more than 40 standardized tests involving changes in population growth and composition, changes in the distribution of employment and shops, changes in travel costs and the transport network, and different sequences of transport investment. The different models were AMERSFOOT, CALUTAS (Computer-Aided Land Use-Transport Analysis System), DORTMUND, ITLUP (Integrated Transportation and Land-Use Package), LILT (Leeds Integrated Land-Use/Transport

Model), MEP (Marcial Echenique and Partners), OSAKA, SALOC (Single Activity Location model) and TOPAZ (Technique for Optimal Placement of Activities in Zones). These models were put through three tests where in the first two the effects of changes in travel speeds and costs respectively on land use patterns are examined. In the third the effects of redistribution of employment are considered. The effects of increased speed on land use were generally quite small except in a couple of places. Within relatively unresponsive land use patterns overall, there were disturbances in some individual sectors of population and employment, and there were substantial movements at a more disaggregated spatial level, than in the extremely aggregate comparisons used in the study. The effect of increase in cost provides a good case of the importance of using a fully interactive land use-transport model to examine transport policy. The third test involved radical relocation of employment and this showed a remarkably small effect on travel costs, time or energy. It seemed that people would still travel as much as ever to maximize their choice of employment. The process of testing the models faces the problem of identifying whether the different responses of the models are due to differences between the cities or due to different mechanisms within the models themselves. But the process does help in identifying the characteristic behavior of individual models, to judge their plausibility and find out aspects that need improvement (8).

In the traditional four-step travel demand modeling process, the number of trips made by a household is modeled in terms of household size, income, and other socio-demographic variables. Any effect of accessibility is usually not taken into account. Some theories suggest that trip rates must vary with accessibility, i.e., location, land use, or transportation service level does play a role in affecting the number of trips and there are some empirical studies which do support this theory while others do not. The independent effects of land use and accessibility variables on household trip rates were tested for using data from Florida travel surveys. After controlling for socio-demographic variables, residential density, mixed use, and accessibility do not have significant, independent effects on household trip rates. Conventional trip generation models, which generate person trips by vehicle (not by all modes), discounting the effect of accessibility, may not be as inaccurate as it is considered to be in theory. But land use and accessibility variables may have some effect on household trip rates, indirectly through their effect on automobile ownership (9).

Models Involving Urban Character Variables

In addition to land use and transportation system variables, it has been suggested that accounting for urban size class, activity concentration, and geographic clusters can enhance model transferability. Based on the nationwide major city characters, several models were developed to estimate trip frequency and trip length. The sample data covered 151 urban areas or 57.6 percent of US SMSAs. The developed models indicate that urban size class and geographical cluster are highly correlated to trip frequency; and urban size class, urban activity concentration, and geographic cluster all affect trip length (10).

Studies show that urban character bears significant influence on travel demand, and the model transferability varies with demand measures and model specification. The specific findings include:

(a) the type of activity concentration has a significant impact on trip frequency for non-metropolitan areas and trip length for both metropolitan and non-metropolitan areas
(b) the influence of urban area size on mode choice and trip length is significant for metropolitan areas
(c) the impact of geographic characteristics on travel demand can be ranked in order to trip length, trip frequency, and mode choice

(d) metropolitan trip frequency models are more transferable than their non-metropolitan area counterparts, while the transferability of trip length models of both metropolitan and non-metropolitan areas is very low
(e) in non-metropolitan areas, non-work trip frequency models are more transferable than work trip models (11).

Individual Choices to General Equilibrium

This approach presents, under a unified, coherent behavioral framework, integrated, static models, under average or steady conditions, which predict all major dimensions of travel behavior, under a spatial structure of analysis. The basic problem of individual route choice under uncontested conditions, for both car and transit passengers, was solved at the individual level, in the deterministic case (when link utilities are known with certainty), from application of "Minimum Cost Route" and its probabilistic version developed by Speiss. In the stochastic car case, the route choice problem was solved from the application of the "STOCH" algorithm. In all cases, the concept of the "representative traveler" was applied to retrieve aggregate route demands providing network assignment as the solution to the representative traveler's utility maximization problem. The stochastic transit case, both the individual and the aggregate levels, is left as a combination of both the methods.

Next, other dimensions of travel demand, including destination, mode choice, route choice (still under the absence of congestion), are combined. This is the expansion of the 'travel consumer' framework. Route choice modeling is then done with more realistic assumption of network and destination congestion. Under the assumption of various travel externalities, the various aspects of travel demand, destination, mode choice and route choice is modeled. A combined equilibrium model of urban personal travel and goods movements in which commodity flows are generated by the need to support a given urban activity undertaken by individual travelers involving consumption of a given commodity is developed. An explicit, full representation of the interacting behaviors of travelers and commodity suppliers and shippers within the framework of spatial competition is presented. Passenger and freight flows take place concurrently on a common congested network, which is used also for general travel. It has been shown that under general conditions, the model has a unique solution and the algorithm for obtaining the solution was described. The model was then extended to the case of multiple trading levels, and of multiple commodities. Finally, the supply side, the demand responsive determination of optimal transportation and equilibrium between travel supply and demand is addressed. It also formulates the network design problem for the car and the transit under congested as well as uncongested condition (12).

From General Equilibrium to Dynamic Planning Models/Evolutionary Models

The assumption of this behavioral model is that supply and demand are not in perfect equilibrium because costs of moving and switching jobs are high and traffic assignment may not be in perfect equilibrium because knowledge is not perfect. Here the demand in a given year depends on the demand of the previous year. The model redistributes a fraction of work trips each year associated with relocation of a household or taking a new job, and changes in distribution associated with growth or decline are considered. The modeling framework considers equilibrium and evolution as two poles with two interim combinations of the methods, depending on decision time horizon evaluated, whether day-to-day or year-to-year. Day-to-day decisions include route choice, mode choice, departure time choice, and non-work trip destination choice. Year-to-year decisions include relocation or work trip (re)distribution for a fraction of commuters, automobile ownership and trip (re)generation. The decisions are not mutually exclusive, so endogenous year-to-year decision reflect changes in the day-to-day decisions. In addition, the system variables like network, land-use and demographics vary annually. The new model component here is the decision to relocate. The model components include trip generation, distribution, mode choice, departure time choice, route choice and intersection control. This approach has the ability to use observed data more easily and thereby limit modeling to changes in behavior. It adds more realism in the concept of the model. It also has provision of a framework to extend and integrate with land use models and makes available additional information to policy-makers (13).

APPLICATION IN STATE AND REGIONAL MODELS

Stockholm Metropolitan Region

A package of large-scale investments in the transportation infrastructure is currently being proposed for this region. It contains new investments in the railway and subway systems as well as new links in the road system. Four different approaches of appraising this kind of investment program have been done and they are related to one another. The first study uses a network-based mode-split/assignment model with a fixed trip matrix. The second study is complementary, as its aim is to also trace the impacts on the spatial distribution of population and jobs by applying an integrated transportation and land use model. The third study looks at the long-run effects of the investments on regional economic growth within the framework of regional production functions. Fourth, an alternative approach is used, in which benefits from the investments are assessed through their estimated influence on aggregate land values (14).

San Francisco Bay Area

A regional travel forecasting model system update using the 1981 Bay Area travel survey and the 1980 census Urban Transportation Planning Package was done for this area. The demand model development process is characterized as a six-step process involving development of component models and the subsequent packaging into an aggregate forecasting system. The MTCFCAST-80/81 forecasting system involved re-estimation of all model components. Simplifications to the original MTCFCAST system were introduced where warranted; the structure of the mobility and work trip models was tampered with the least. In contrast, the work-trip mode choice model was expanded to distinguish between two-occupant and three-plus-occupant carpools, in support of travel forecasting for high-occupancy-vehicle lane projects. Continuity is seen as the key to maintaining and updating regional travel demand model systems (15).

Tiete-Parana Valley in Brazil

The Multicommodity Multimodal Network Design model was used as a planning tool for determining investment priorities for freight intercity networks. The pilot application of the model to assess its efficiency when dealing with large networks at the Tiete-Parana Valley in Brazil indicated that the model was able to simulate accurately the flow of commodities on a large, real network. A new implementation of the solution algorithm within a parallel processing framework was being developed to turn this model into a practical tool.

The basic concept of the MCMND model was based on the assumption that this model would be used as an analytical tool in the process of planning transportation infrastructure investments at a strategic level in developing countries. This calls for a complex level of detail for the representation of the transport services provided in the medium to long-term planning. The multimodal network was characterized as a set of nodes, physical arcs, and logical arcs. The physical arcs connect nodes representing cities, rail yards and stations, river ports, other types of transfer facilities and sometimes the intersection of two different road segments. Logical arcs result from the expansion of zone centroids as well as transfer nodes located at the intersection of arcs representing different modes. The logical network starts with the transformation of each zone centroid into two logical nodes, for demand

and supply. Then a logical node is constructed for each mode that enters or leaves a node. Finally loading and unloading arcs are added to link supply and demand logical nodes to each logical node-mode combination, as well as the intermodal transfer arcs. The demand for transportation services was assumed to be fixed and exogenous to the model. Mode choice in shipping freight was modeled in combination with traffic flow assignment, using the assumption that goods are shipped at minimum total generalized costs. A simple interface was designed to link the MCMND model to TransCAD. This interface consists of a file interchange scheme between the model's solution algorithm and TransCAD. It simplifies the data input-output process and also allows users to visually evaluate the distribution of freight flows over the network, the addition of new links, location of transfer facilities and ultimately the effect of alternative design options. A new path-based stochastic user equilibrium assignment algorithm was proposed to distribute trips over the multimodal network according to a logit-type model (16).

Quad County, Washington State

A study conducted for the Quad County Regional Transportation Organization in Washington State demonstrates that traditional urban transportation planning techniques can be applied in perhaps a new way to perform detailed analysis of freight movements. To accommodate more refined analysis of goods movement, the traditional modeling process required a number of modifications. The first step of the process included the traditional modeling approach to forecasting vehicle trips, the second step involved detailed assessment of agricultural freight moved and the third step was the approach used to model special generators, in this case, primarily recreational travel. Distribution patterns of the agricultural goods were noted and detailed information on crop distribution helped develop an input-output matrix that was converted into a trip table by making it conform to the transportation zone system. Goods movement was converted from tons to truck, rail or barge trips. The trips were assigned to a highway network developed and microcomputer based transportation planning software was used. The model was used to evaluate the future changes in traffic volumes and goods movements by mode. The basis for these forecasts was the estimates of activities within each land use sector. Growth related projections were then converted into estimates of vehicle and freight movement using the transportation model. External trip growth was also estimated. This study highlights the point that rural transportation focuses on farm-to market and roadway conditions instead of capacity issues. It is also an example of how quick-response methods (similar to those described in NCHRP Report 187) were applied to enable the project to be completed within 6 months at a lower cost. In fact, it highlights the fact that truck and tonnage can be modeled using techniques similar to those developed for urban transportation vehicle models (17).

Metropolitan Region of Dortmund in the Federal Republic of Germany

The International Study Group on Land-Use/Transport Interaction (ISGLUTI) conducted a study for the metropolitan region of Dortmund in the Federal Republic of Germany. Three land-use/transport simulation models were applied to the Dortmund region: the DORTMUND model, the LILT model and the MEPLAN package. The three models are briefly characterized and their ex-post forecasts are compared with the actual development of the region. The study compares how the three models respond to a common set of assumptions and policies from the fields of land-use control, traffic management and transport investment. The differences in model response give insights into the validity of the theoretical foundations and internal structures of the model (18).

Southeastern Wisconsin

A method was developed by the Southeastern Wisconsin Regional Land Use Transportation Study (SEWRPC) for the estimation of modal split land use plans and application of this method in plan preparation. The method was developed specifically for regional planning purposes and has greatest applicability as a broad, area-wide transportation planning tool. The modal split mathematical model assumes that the variables, which presently influence the level of transit utilization, will do so in much the same manner in the future. On the basis of the tests performed on the model, it was concluded that the model replicated the actual transit utilization pattern within the region with accuracy. In the regional, district and zonal levels, the model was found to estimate satisfactorily the transit utilization rate and number of transit trip productions for the four trip purpose categories: home-based work, home-based shop, home-based other and non-home-based (19).

Toronto Area

The main objective of the Toronto Area Regional Model Study (TARMS) was to develop a traffic forecasting model to be used as a long range planning tool for the study area. The TARMS model had three major components: trip generation, trip distribution and modal split. In order to establish more precise and reliable relationships between trip making and land use, the trip generation process has been carried out by trip purpose. The TARMS model is in two parts: a 24-hour model to simulate daily person trips, by both private vehicle and public transit for long range planning purposes, and a PM peak model to simulate trips between 4.30 PM and 5.30 PM for system purposes (20).

Auckland Strategic Planning Model

The Auckland Strategic Planning Model (ASP) is a new generation interactive land-use transport model designed to investigate strategic futures for Auckland over a 30 year planning horizon. The ASP model has enabled, for the first time, the real integration of transport planning with both land-use planning and environmental management within Auckland. The ASP model provides consistent projections of future urban activities for input into transport models for Auckland. It also represents the interactions between land use policies, transport policies, infrastructure investment, and development controls and their impact upon urban form and the transport system. The ASP model consists of a location model for households and employment, a transport model, a regional demographic model, a model of regional employment growth and an evaluation module (21).

The Urban Transportation Modeling System (UTMS)

The Urban Transportation Modeling System (UTMS) is used to forecast travel demand in response to changes in land use patterns, roadway characteristics, and socioeconomic factors. This demand is measured by the volume of traffic that flows through a system of streets and highways. Regional and local area models are developed to respond to different issues, though they share a common pool of information regarding the physical characteristics of the network, as well as the demand for travel. Traditionally, the sharing of information between regional and local models has been a one-way flow.

Through the use of traffic assignment software, parts of UTMS have become automated. One of the newest automated processes is the extraction of a sub-area from a larger regional model. This extraction process is important to the local planner because it maintains a link from the regional model to the local model and allows the planner to extract an already distributed trip table rather than build one from scratch. This sub-area extraction process, as practiced, is a one-way information flow. Network and travel demand information from the regional model is extracted and used as part of the development of the local area model. The regional model is calibrated and its information is passed down to the sub-area model. There is a need for the "information feedback loop" to be inserted into the process, to improve the regional model. The sub-area model information is looped back to the regional model and used in the regional calibration. This improvement benefits both the regional and local levels.

The enhanced process was applied to a case study in northern New Jersey. The results showed that the new methodology improved the calibration of the regional model, particularly in the vicinity of the sub-area focus model. This improved calibration process is the key to developing sub-area focus models with properly distributed trip tables. The new methodology would work at all levels of the modeling process. This would mean that planners collect data specific to their area and replace these new attributes back to the regional model, attempting to gain a better calibration for their specific area. Once the local planner processes this information, the data could be channeled back to the state DOT. Modification can be then made into the statewide modeling chain and translated into new link attributes or new coefficients for production and attraction equations. This process would mainly contribute towards consistency and greater frequency between calibration updates and thus lead to better forecasting (22).

DEFICIENCIES OF EXISTING TRANSPORTATION PLANNING MODELS

The most important problem in transport modeling is the lack of coordination between theoreticians and practitioners. Practitioners need answers to problems in the time period available for study, i.e., usually in the short run. They generally tend to adopt a pragmatic modeling approach reflecting the limitations of data, time and resources available for the study. On the other hand, theoretically sound models might be difficult to implement, though they might guarantee stable results, consistency and add confidence in forecasting. Theoretically sophisticated models can be too complex and this implies that heuristic approaches, rules of the thumb and *ad hoc* procedures are sometimes preferable. Model output needs interpretation and this is only possible if reasonable understanding of the basis for such model is available. Good publications bridging the gap between the practitioner and the academic are an urgent need. Use of model criteria depends on the nature of the problem, the level of detail needed and the context of the problem. So the aim of the modeling approach should be to use good, sound models as far as possible, even if it means sacrificing some level of detail. The best balance between theoretical consistency and expediencies each particular case and decision-making context has to be found.

The Atlanta case study brings out the drawbacks of the traditional urban transportation process (23). The lack of specific goals that influence the nature of estimation methods employed is often a drawback in aggregate analysis. The policy sensitivity of the procedures highlighted in this case is inadequate to suggest the possible impacts of a specific transport design on the attainment of the goals. In most cases there may be direct trade-off where one goal is achieved at the expense of the other. In this case, the focus on circumferential, limited access highway construction and improvements enhances the mobility of the suburban areas but at the expense of reduction of accessibility of central-city residents to the economic opportunity that has been fostered by the outer belt. The goal in this case was provision of accessibility to all of Atlanta's resources, energy conservation, minimization of undesirable environmental impacts and effective transportation to the handicapped and elderly. There is an apparent lack of connectivity between goals and methods.

In analyzing trips generated, the number of trips leaving an origin zone is modeled as a function of automobile ownership; household size and accessibility are not considered. This implies that changes in the trip frequency are independent of changes in the transportation system. The same problem lies at the level of trip attractions. In the trip distribution model (the gravity model) in this case, had the impedance factors based on trip duration as measure of automobile travel, so changes in provision of improved transit service and associated impacts cannot be accurately assessed. So, in this case planners are not in a position to predict accurately the spatial distribution of travel demand under the new equilibrium where Atlanta's travel times have changed through changes in the transportation system. The basic flaws outlined in this study were the requirement of better goals, linkages between forecasting methods and policy sensitivity and the ability of planners to assess the effects of transportation alternatives on goals.

The behavioral approach to transportation modeling, which reflects disaggregated or individual demands, involves assumptions about individual objectives, opportunities, constraints etc., as in microeconomic analysis. It grounds travel demand analysis in an explicit, rigorous framework in which individual travel behavior is explained as a rational outcome of an explicit decision-making process of the individual travelers, under specific conditions. This approach has a sound theoretical base, but it is very contextual, i.e., this model might not be applicable to a whole lot of situations, since the basic assumptions on individual choice behavior might differ. There is need for a more universal approach, which encompasses individual travel behavior but at the same time can be modified and applied to almost all situations. The issue is of flexibility of models. This also brings in the issue of "feedback" into the modeling process and the effect of it on the results. This would in reality mean a large number of iterations in the model to converge. This is essential to adjust the models to changing times and their effect on the various aspects of transportation. This implies incorporating different other impacts on the transportation planing process, integrating the transportation modeling process with that of other models of regional impact analysis, environmental impacts, energy impact, etc. The other very important issue is the distribution of impacts of transportation investment spatially, and the issue of equity. The modeling process should incorporate the cost-benefit analysis into the process, in order to get the best alternatives and assess the impact of the competing alternatives. This would give a broader view of the impact of the transportation planning process to the planner to help in decision making.

CONCLUSION FROM HISTORICAL OVERVIEW

The transportation planning process has made considerable progress in recent years in terms of technology used and also theoretically. Some deficiencies in the earlier modeling approaches have been addressed in some models. But a universal, integrated model, in which all these deficiencies are addressed, is yet to be developed. This model would require an integrated system of sub-models, ranging from economic models, regional impact models, environmental impact assessment models, cost-benefit assessment models and others.

TRADITIONAL TRANSPORTATION INVESTMENT ANALYSIS MODELS REVIEW

Weisbrod and Weisbrod (25) compared the various techniques for economic impact analysis of transportation projects. Such analysis guides decision-makers of public investments and ensures that they recognize both positive and negative economic effects of potential projects. Direct economic benefits to residents affected by transportation projects include increased income from sales to non-residents, lower costs of products and services, and increased opportunities for work and recreation because of greater accessibility. Likewise, businesses benefit from greater product availability, in terms of costs and quality, greater access to labor markets, and lower costs of delivering finished goods. Indirect impacts may be growth of business suppliers, while induced impacts may be additional business from greater numbers of local employees. There could be further induced changes in business locations and population shifts, both of which will affect land use patterns, wealth, environment, "quality of life," and the revenues and costs of governments in the area affected.

The elements of impact of transportation projects are summarized by Weisbrod and Weisbrod as spending (on construction, maintenance and operations) and user benefits (in terms of time, cost, and safety). These have interactions with:

1. Growth of economic activity (sales, jobs, wages, value added)
2. Overall growth of economic activity (includes multiplier effects)
3. Land development (land use, property values)
4. Fiscal impacts (government revenues and costs)
5. Environment and quality of life impacts.

The interactions in the different levels of impacts lead the authors to be concerned with "double counting" of benefits, ignoring the potential for some business gains to be offset by losses elsewhere. While the analysis focuses on economic benefits (leading to increases in income), it is recognized that projects may also have non-economic or social benefits (the "quality of life" discussion).

Stepwise Approach

In their guide for planners, Weisbrod and Weisbrod begin with formulating a statement of the transportation project, in terms of mode (freight vs. passenger, infrastructure, vehicles, services), service area, type of change (upgrade, expansion, maintenance, or new mode), and purpose (ease congestion, link existing activities, future demand, new development, quality of life). Then comes the purpose of the analysis, which may be to measure impacts, provide public information, produce the benefit-cost analysis, or conduct a research study of users. The types of analysis will vary, depending on its purpose, as will the "base case," which may assume either a change from existing conditions, a continuation of existing conditions, or if the base case is a time prior to the existing conditions.

Selecting the appropriate geographic study area "causes more error or confusion in economic impact analysis" than any other subject, according to the authors. Analysts should consider the sponsoring agency's jurisdiction, the area the project influences directly, the distributional impacts of "socially desirable" goals and "dis-benefits," and external consequences (25, page 13). The time periods for analysis of the effects of transportation projects vary from one year to the lifespan of project.

Impact Measures

Four different categories of impact measures are listed. User impacts include the money cost of travel, travel time, safety, and intangibles such as comfort and reliability. Total user benefits would be the combination of these impacts. User impacts may be used for impact assessments and benefit-cost analysis of a proposed new transportation service.

Economic impacts are measured by employment, personal income, property values, business sales volume, value added ("personal income plus business profits"), or business profit. Only one measure should be used from these alternatives. Several of the economic measures are used in impact assessment of new service. In addition, employment, personal income, and business sales volume are acceptable for public information about new or existing transportation services. Benefit-cost analysis for new services may use personal income, property values, or value added as measures.

Government fiscal impacts are the combination of public revenues and expenditures. The fourth category is a combination of other societal impacts, including air quality and other environmental and social conditions. Both of these impact measures may be used in analyzing the impact of proposed services (25, page 15).

Benefit Measures for Benefit-Cost Analysis

The traditional transportation system efficiency measure is user impacts, a summation of travelers' cost and time-savings (expressed in monetary terms, estimating a value of time), and safety benefits. Since benefits to all users (including those passing through) are included, the benefits to residents may be overstated. Benefits are understated to the extent that nonusers are not included although they see an improved quality of life from having a greater selection of goods and services, or increased property values).

The most common measure of economic benefit is personal income. It includes changes in wage incomes earned by both users and nonusers within the study area. Weisbod and Weisbod consider it a reasonable measure if most of the affected workers live in the study area. However, since some of the increased business income may be paid outside the area, the true impacts are underestimated. Likewise, the benefits to time savings are undercounted unless they lead to changes in business activity.

Value added (gross domestic or regional product) might be "the most appropriate measure of impact on overall economic activity in a geographic area" (25, page 16). It does include business profit that may be paid or reinvested to owners outside the region, thus overestimating the true economic impact. Personal income may be preferred as a more conservation measure of benefits to area residents. Both value added and personal income underestimate the benefits reflected by increased property values which may be induced by transportation projects that deliver cleaner air or a greater selection of opportunities for education, recreation, social interaction, shopping, and jobs.

A hybrid measure of societal benefit might be formed by the combination of business travel benefits (overall income generated) and non-business travel benefits (in terms of "willingness to pay"). The authors warn that obtaining valid data on the latter is "potentially problematic" (25, page 17).

Methods of Analysis: Transportation Models, Economic Models, Direct Measurement

Three types of analytic tools may be applied. These are transportation system models, economic models, and direct measurement techniques. Transportation system models simulate and forecast trip generation and routing, modal split, and travel times and costs due to the effects of transportation services and facilities. Economic models are grouped into three types: input/output models, general equilibrium simulation models (which include input/output impacts and changes in business productivity, competitiveness, and growth because of changes in travel costs), and business attraction and tourism market models (which forecast the effects of transportation linkage enhancements). Direct measurement techniques analyze historical data to measure the effects of transportation facilities and services.

The first type of transportation system model is supply side modeling, which produces either a "full simulation model" or a "sketch planning model" of a portion of the transportation network.. Alternative scenarios describe capacity, projected volumes and trip distributions, plus performance. Outputs will be users' travel times and costs, links (routes), and nodes (terminals or points of transfer). Net changes are measured in terms of vehicle-miles of travel, passenger-miles of travel, vehicle-hours of travel, and passenger-hours of travel (VMT, PMT, VHT, and PHT, respectively).

Pratt and Lomax present a somewhat expanded list of performance measures for multimodal transportation systems. Travel time was redefined as desired door-to-door travel time, but also divided into segment or trip length. One of the authors' major conclusions was that planners should employ both mode-specific measurements and multimodal measurements, rather than rely on the latter. Time and distance affect average speed (overall), and average and desired travel rates. Segment volumes are also defined for both vehicles and persons. The performance of intermodal terminals is measured by time or difference in travel time, by delay rate, total delay, relative delay rate, and delay ratio. The authors advise planners to match objectives with performance measures and not let concerns for data govern the development of measures.

Compared to the shipping patterns of the various modes that are identified in supply side analysis, the unique shipping patterns of of different types of businesses are explained in demand side analysis. Outputs will be trip volumes, both current and projected, origin-destination pair, for alternative scenarios. Traffic patterns, volumes and times, by link and node, are estimated by software such as EMME2, MINUTP and Tranplan (25, p. 18).

Input/output models and macroeconomic models are the two basic types of economic models used for transportation project analysis. Input/output models generate multipliers of incomes, jobs, and output for each dollar of project spending. Examples of software based on input/output models are IMPLAN, RIMS-II, and PC I/O Model. Econometric and general equilibrium models are in the macroeconomic simulation category. The REMI model and a model by DRI-McGraw Hill are examples of available software. Economic models would be used to estimate how a project may affect jobs and income, based on the changes in travel times, travel costs, and business costs that are estimated by the transportation models. The integration of the two models may need to be reiterated if the economic model forecasts significant shifts in jobs or population resulting from the proposed transportation project.

More a feedback measurement than a planning step, direct measurement of impacts surveys travelers and businesses to document impacts of a transportation project. Secondary data is also used for tracking changes in income, employment, and property values.

Economic Impacts: Project Costs, User Benefits and Economic Benefits

Two categories of project costs are addressed in calculating a project's economic impacts. In addition to the costs of construction and property acquisition for highways, other rights of way, and facilities, the costs of ongoing operations must be included. For example, maintenance and periodic rehabilitation of highways cost between $6,000 and $10,000 per lane-mile (25, p. 20). User (or travel efficiency) benefits, in terms of cost savings, time savings, and safety, should be calculated for "existing trip" users and "diverted trip" users, that is, those who would switch to the new service or facility. A third group, "induced trip" users, are new trips because of the project; their benefits per trip are typically estimated as one-half the exiting user benefits. While benefits are assumed positive, they may be negative during construction and for congestion.

Past experience has provide some typical figures for valuing benefits. Vehicle operating costs are stated on the basis of dollars per 1,000 miles, and vary by vehicle and average speed. Time savings are also translated into dollar values which differ by vehicle type (tractor-trailer or single unit truck or automobile) and by trip purpose (work-related or nonwork). Safety improvements are likewise accounted by estimating fatalities, injuries and property damage per 100 million VMT, and converting those to dollar figures using published average costs. Such estimations may appear overly simplified but they do add a degree of consistency of analysis, necessary when results from several projects are to be compared.

Economic benefits are grouped into three classes. The first is jobs directly resulting from construction and ongoing activities connected with the transportation project. Second are the direct project benefits, in terms of travel and logistics efficiencies, economies of scale, and availability of goods and services. The third category is indirect and induced impacts, also known as the multiplier effects. For example, the "job multiplier" would be the number of new jobs in the area per each new job in a specified industry in that same area. Published multiplier values are between 1.5 and 3, depending on whether local, state or national impacts are being considered (25, page 24).

Output Considerations

Results may be stated as single-year impacts or a stream of benefits over a longer time period, e.g., the life of a project. Weisbrod and Weisbrod caution users against double- and under-counting of impacts, and to be clear in stating dollar amounts in either constant or nominal terms; they recommend constant or deflated reporting as being better understood by the public (25, p. 25). Likewise, job impacts need to be clearly stated as to their time horizon, single year vs. recurring over time.

Benefit-Cost Analysis

Both benefit-cost (B/C) analysis and the net present value (NPV) method use the present value of benefits and costs, but B/C ranks projects by the ratio of benefits to costs, while NPV ranks them by magnitude. Thus, a small project with a very high B/C ratio would be rejected in favor of a larger project that had a positive NPV but a lower B/C ratio. Because of uncertainty with both benefit and the cost estimates, planning agencies may require threshold of B/C ratios greater than 1. Selecting the discount rate is described as "an important and controversial policy issue, reflecting political values" (25, p. 26). Using the criterion of "opportunity cost of capital," alternative measures include the cost of borrowing money (interest rate paid by the public agency), the real rate of return possible in the private sector that the money could have earned in the private sector (the interest rate paid in the private sector), or the more conceptual rate expressing peoples' preference for money now instead of future returns. Discount rates typically range between 4 and 8 percent, with 7 percent recommended as matching private sector returns.

Other considerations not included in B/C analysis include feasibility and cost-effectiveness. The resources, in terms of money and technical abilities, need to be available for the project to be feasible, regardless of its calculated B/C ratio. For projects without benefits expressed in monetary terms, a cost-effectiveness measure may be applied. For example, expressing costs in amount per unit or per person served will provide an unambiguous measure and an objective more clearly stated than a goal such as "Improve existing transportation service."

An application of benefit-cost analysis in an intermodal setting was described by Jayawardana and Webre (26). Development projects at both private and public ports were eligible for support from a state's Transportation Trust Fund. An overall ranking of projects used the benefit-cost ratio as the most important criterion, with the highest ratio project receiving 100 points on a 200-point scale. Additional points were given for technical feasibility (maximum of 45 points), economic impacts, in terms of jobs created or saved (20 points), environmental impacts (10 points if no adverse effects; 15 points if a project would enhance the environment), and management of the port (20 points for greatest return on investment). The added criteria, some of which may be viewed as already being included in the benefits or costs, were to accommodate a range of interests from a diverse group of public and private sector "stakeholders," including legislators and representatives from various modes and deep-water and shallow-draft ports.

INCORPORATION OF LOGISTICAL SYSTEMS IMPACTS

Transportation planning is undertaken at many levels, from strategic planning to project planning, and over various geographic scales. During the last forty years, urban transportation planning has undergone many changes and continues to evolve. But many of the notions developed in the early years still exist. The basic urban transportation planning process usually consists of three interrelated major components: the pre-analysis phase, the technical phase and the post-analysis stage (14). The pre-analysis stage involves identification of problems or issues, formulation of goals and objectives, data collection and generation of alternatives. The problem definitions need to be broad enough to accommodate a considerably larger set of possible solutions. The technical phase involves mathematical descriptions of travel-related behavior, used to predict the consequences of each alternative transportation plan to be evaluated. It consists of three major components: the land use-activity system model, the urban transportation model system and the impact prediction models. The land use-activity system models are comprised of the spatial distribution of people, activities, and land use within an urban area. These are now integrated with transportation models to assess its impact on travel. They help predict urban activity patterns and generally use regional population and employment as inputs and distribute these totals spatially over a region. The Urban Transportation Model System (UTMS) consists of models commonly used to predict the flows on the links of a particular transportation network, as a function of a land use-activity system that generates travel. The sub-models are that of trip generation, trip distribution, mode choice and trip assignment. The UTMS predicts the quantity and quality in terms of travel time of flow on the links of a specified transportation network, given the land use-activity system as the input. Assessment of alternative options needs estimates of a broad range of impacts, including construction and operating costs, energy consumption, and air quality. The impact prediction models basically need the UTMS as its input. The post analysis phase starts with the output of the technical analysis that is comprised of predictions of the impacts of alternative plans and policies. This phase involves evaluating both the economic and non-economic impacts of the alternatives analyzed; selecting the alternative to be analyzed; programming, budgeting and implementing the alternative chosen; and monitoring of the system performance.

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CHAPTER 2

THE APPLICATION OF GIS TO MULTIMODAL INVESTMENT ANALYSIS

INTRODUCTION

Transportation modeling activities have traditionally recognized that movement through transportation networks is complex, especially when considering configurations of several modes of travel (1). Current and historic patterns of mode choice are used to dictate mode split, or the proportion of trips that will be undertaken by each available mode. Agricultural products are transferred by truck, rail, and waterway. Passenger travel is accomplished by private automobile, public transportation (rail or bus), airplane, waterway, and bicycle. Multimodalism considers the contribution of each of these modes to the overall movement patterns of people and goods, while intermodalism considers the interconnectedness of these modes. Along with the consideration of a multimodal system, models extended to account for social, economic, environmental, and aesthetic opportunities are referred to as "unified", "integrated", or "comprehensive" (2).

In reality, movement of people and goods does not occur solely on the basis of a single mode. In other words, grain may be moved from the field by truck to a storage location. From the storage location it may be moved by train to a processing plant and ultimately delivered by truck to stores or consumers. Trip chains for passenger travel can also involve multiple modes. A work trip commute might involve driving an auto to a rail or bus stop, with the possibility of additional transfers within or among modes to complete the trip. A significant new improvement to modeling efforts can calculate modal transfer links based upon spatial and temporal proximity (3). In this way, travel activity modeling can be more realistically simulated.

Visualizing transportation networks, especially involving multiple modes is very cumbersome in a non-graphic environment. A zonal trip time/distance matrix by mode can be constructed, however, without an explicit spatial element. On the other hand, a (geo)graphical map that defines network topology is not only more easily interpreted in geographic space, but it also defines the relationships between the transportation network and surrounding activities such as population densities, employment locations, and land use patterns. These activities are factors in dictating not only the level of transportation demand, but also the spatial distribution of movement, as well as the modal requirements of transportation demand. The spatial arrangement of transportation demand and supply of transportation facilities are perfectly suited for a geographic information system (GIS) environment for visualization purposes and also for the data management requirements associated with both demand and supply characteristics.

The purpose of this paper is to highlight the key issues involved with the application of GIS to multimodal investment analysis. As will be discussed, there are considerable data requirements involved. GIS offers a variety of analytic functions that enhance data base management activities as well as spatial analysis. Using GIS for multimodal investment analysis will merge transportation network analysis with regional economic impact modeling. This represents an innovative use of GIS, especially in the area of feedback between travel patterns and economic activities. GIS technology is still evolving, with advancements in modeling capabilities currently in the development stages. Advances in GIS, along with tremendous improvements in computing speed, graphics quality, and Internet accessibility may change the face of modeling activities in the near future.

ROLE OF GIS IN TRANSPORTATION MODELING EFFORTS

Transportation demand analysis has been greatly enhanced by the use of GIS. Using travel demand characteristics such as population, employment, and land use, "what-if" scenarios can be tested (4). The graphical, map-based interface provided by GIS enhances data input and management capabilities. GIS data aggregation functions can be used to easily assign demand characteristics to nodes on a transportation network. Once transportation demand indices have been associated with nodes, the data can be ported to an urban transportation planning system (UTPS) package such as TranPlan. After the modeling procedure is completed, results are transferred back into the GIS for graphic display of projected traffic activity. One of the most common uses for GIS in modeling continues to be the display of transportation system attributes (5).

Other uses of GIS for transportation modeling include traffic analysis zone and transportation network generation. Polygon analysis (overlay and buffer) can help to determine optimal zone sizes and geography. Two objectives of traffic analysis zone construction are homogeneity and contiguity, which can be easily tested with a GIS (6;7). When zones define areas that exhibit homogenous household and land use characteristics, transportation demand can be more effectively predicted. In addition, the network topology capabilities of GIS assist in transportation network preparation. Operations such as ArcInfo's "clean" and "build" operations can determine whether network links are complete and continuous.

GIS AND REGIONAL ECONOMIC MODELS

Regional economic modeling has been traditionally carried out with limited spatial specificity. Economic characteristics for each geographic unit (e.g., region, state, county, MSA, city) along with the likelihood of each region to interact with other regions, are the foundation for analysis. Conceptually this can be structured in a matrix format, where geographic space does not need to be represented realistically (i.e., map form). Instead, cells of the matrix signify discreet geographic units and the attribute data provides economic, social, and spatial definition. Although such a model includes a "distance decay" factor for spatial interaction, the distance measure is commonly a straight-line distance or average travel time or distance by a single mode along a fixed route or shortest path. The optimization of travel routes or transportation facility usage levels do not have a high level of importance in the modeling process. Transportation modelers predict movement patterns and economic modelers predict levels of economic activity. The convergence of these two efforts could produce a valuable, integrated analytic tool. There are few published examples of GIS applications for regional economic analysis that consider transportation infrastructure; following is a summary of three examples.

Brooks, London, Henry, and Singletary (8) employ GIS to analyze the impacts of infrastructure investments on employment and income distribution. In the case of transportation investments, the GIS is used to calculate highway density measures for each of the Census County Divisions (CCDs) in the state of South Carolina. Their results suggest that highway accessibility has a significant impact on employment levels. An input-output (IO) table was then used to estimate employment impacts related to output and income effects. The resulting model can then be used to simulate the impacts of proposed highway improvements on employment and industrial output.

In 1994, Hartgen and Li (9) reported about the use of GIS for transportation corridor analysis in a 10-county rural area of North Carolina. Their research estimated the growth impacts of interstate exits following improvements to the roadway. They also analyzed the impacts that resulted from decreasing travel times from manufacturers to shipping points and also for changes in commuter sheds because of increased accessibility. Using the GIS they were able to generate forecasts of travel volumes which then impacted assignments. Their analysis, however, did not consider multiple mode choice opportunities.

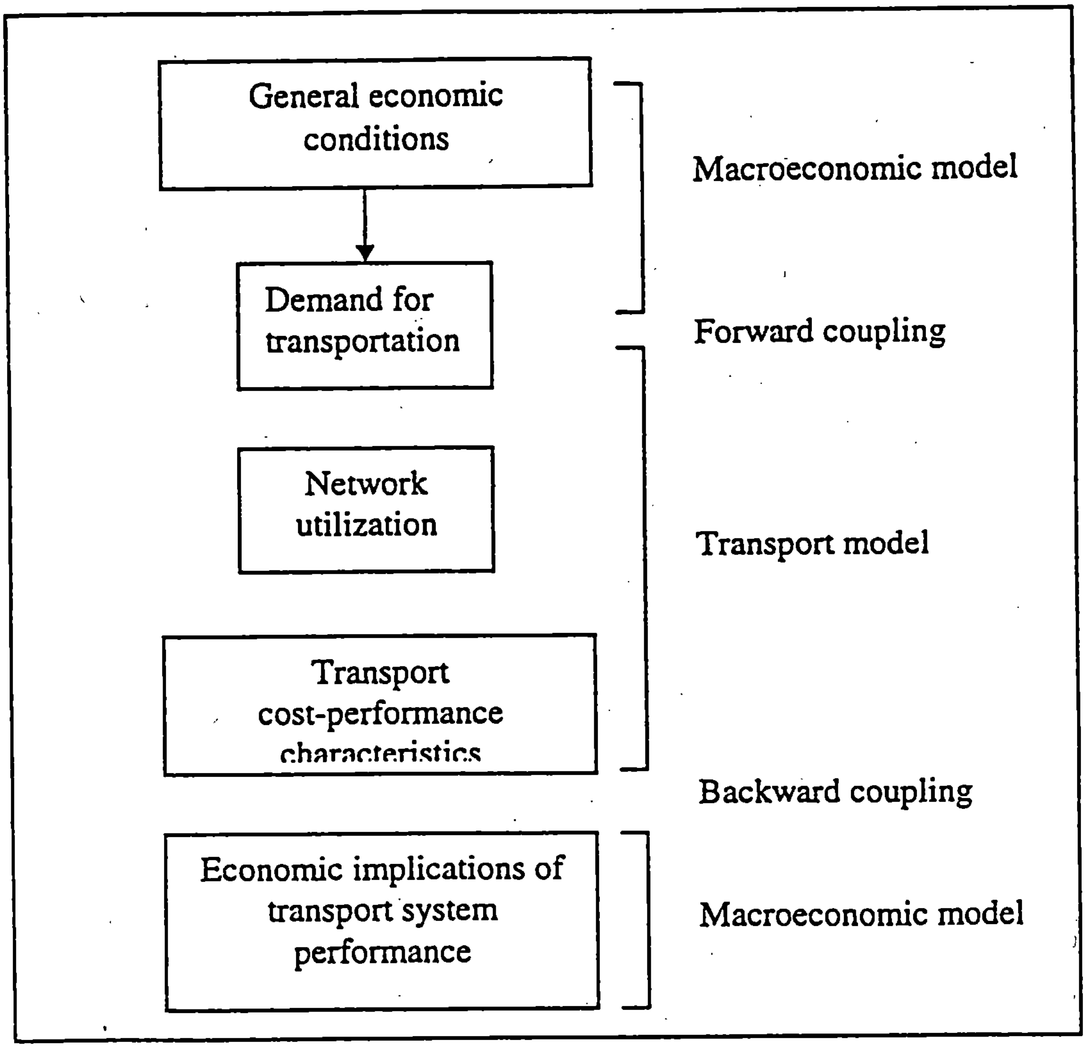
In a third article, Nyerges (10) provides a thorough description of the transportation modeling process that accounts for region-wide population, employment, and household forecasts within a multimodal framework. He describes GIS support for travel demand forecasting in the Puget Sound Region of Washington. As is common to the demand forecasting process, the assignments and mode choice are iterative, however, the economic impacts to the region have no explicit feedback function to the regional demand element. Exogenous forecasts for employment and residential growth are supplied at the traffic analysis zone level.

Overall, the use of GIS in regional economic modeling efforts is primarily for data generation and integration purposes. The complexity of economic impact assessment related to transportation investments has been recognized by researchers (11). Most of the actual forecasting is performed external to the GIS with traditional modeling operations such as IO analysis. The missing element here is the true integration of transportation modeling with regional impact assessment, which then feeds back into transportation demand. The pieces of this process currently exist, however, the methods for integration have not yet been fully developed.

SUB-MODELS AND FEEDBACK

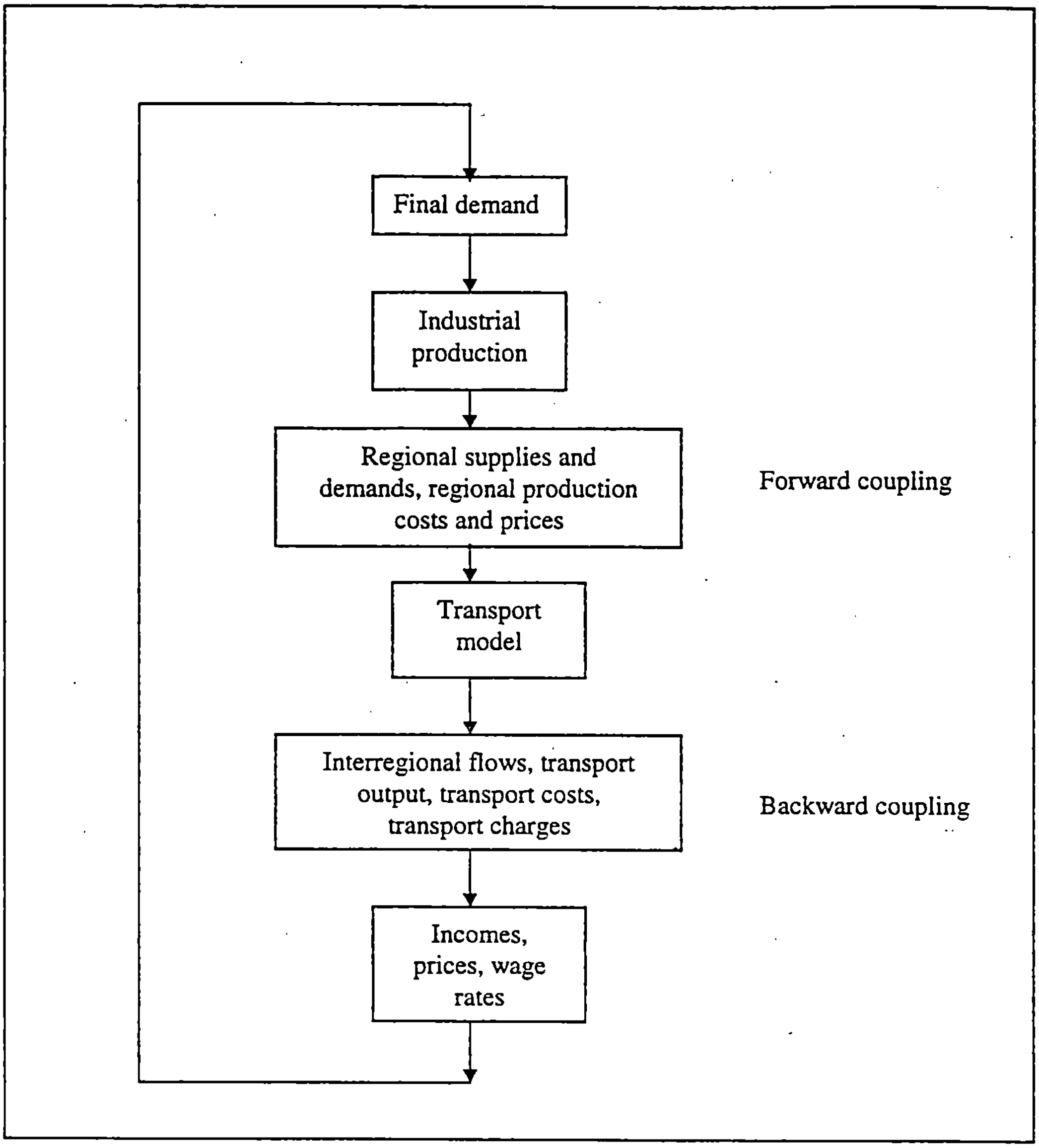
It is likely that a model analyzing regional demographic, economic activity, and a multimodal transportation network will be comprised of several sub-models. Estimates of zonal population change, industrial output and capital investment will be used in order to predict impacts of transportation system alternatives. The issue of simultaneous interactions has been only minimally addressed in the transportation and regional economic modeling literature. Economic development generally occurs in anticipation of infrastructure investments or as a function of the benefits of existing facilities (12). One relies upon the other. A transportation facility in itself cannot create economic activity without the existence of other inputs. Not only are there interactions between transportation investments and population and economic activities, but also among demand characteristics. Population changes are effected by industrial locations. Industrial locations depend upon labor availability. Industrial location activities rely on the availability of other industries in order to achieve agglomeration thresholds, and so on. Each of these relationships becomes a sub-model within the overall regional investment analysis structure.

In addition to sub-models, feedback becomes an important issue in the modeling process. Similar to the way that traditional UTPS operate in an iterative fashion, incorporating changes in congestion levels to affect traffic assignment to network links (13), a regional transportation investment model needs to incorporate feedback from changes in economic activities that produce transportation demand (14); see Figures 4 and 5. Impacts of transportation investments can typically occur over many years and produce changes in business investments and residential development patterns. These changes then impact transportation network utilization by increasing or decreasing spatial demand levels. Other research has focused on analysis zone definition as also having an impact on feedback opportunities (15).



Source: Kresge and Roberts (1971).

FIGURE 4 Components of Macroeconomic Transport Systems Simulation



Source: Kresge and Roberts (1971)

FIGURE 5 Functional Components of the Macroeconomic Model

Sub-models (or the full model) could be made available at the point of data entry so that users (data inputs) could test their data or generate estimations or projections based upon their current data. Each user controls his own layer of data but can also view and manipulate other layers while not modifying them. New data providers (users) would be added as a new layer of information. In order to establish a new user (layer), criteria will need to be structured regarding (a) geography, (b) time series/interval, (c) meta data, and (d) type, such as economic, environmental, network, and social.

ADVANTAGES OF GIS

Researchers have identified many advantages of using GIS for transportation modeling. The primary advantages include speed, analytical capabilities, visual power, efficiency of data storage, integration of spatial databases, and capabilities for "finer-grained" spatial analysis (16; 17, 18). By its nature, geographic information is rarely beneficial to only a single user or location. Typically geographic attributes are common to region-wide locations. Initial start-up investments in GIS usually involve large investments in base map layers of geographical data. For example, cities will often want countywide data because planning activities usually account for extra-jurisdictional areas to accommodate growth. Environmental data is typically collected and maintained by a state or regional organization, transportation facility data is handled by state, county, and/or local agencies, business data may be available locally. It is not unusual for these different types of data to be collected and reassembled by individual users. This may be a function of different data needs related to accuracy, software compatibility, and geographic resolution among organizations. A GIS can serve to integrate all of these data types from different data sources (19).

It is not unusual for users to be unaware of available data that meet their operational requirements. Better communications, coordinated data collection efforts, and information exchange can in the long run lead to cost savings and better decision-making (20). Dueker and Vrana (21) generally refer to these as efficiency, effectiveness, and enterprise benefits. Agency efficiency and effectiveness benefits are most commonly discussed in the literature. The third type of benefits, enterprise benefits, take the form of overall information management activities within an organization. An example of interagency cooperation that can produce enterprise benefits is the case of the Pennsylvania Department of Transportation (PennDOT). The process that PennDOT used in constructing their GIS system included input from the state departments of agriculture, commerce, community offices and environmental resources, the state data center, state library, and governor's office (22). Such a comprehensive approach in the initial phases of database construction anticipates future data integration and sharing opportunities, as well as providing the collective experience to establish a durable GIS system. By having access to an increased amount of information, individual organizations can enhance their own data resources. Spatial data when combined or overlaid can result in a synergistic effect - the combination of layers is more valuable than the sum of the individual layers (23). This type of data enrichment is another benefit that can be realized by organizations that share data.

GIS TOOLS — ACCESSIBILITY, GRAVITY MODELS, SPATIAL INTERACTION

The movement of people, goods, services, resources, and information all happen within identifiable network systems (24). The measurement of accessibility can take on a variety of operational forms - based upon assumptions of the attraction between origins and destinations (gravity) and ease of movement through the network. One of the most fundamental forms is referred to as "relative accessibility", where the distance or cost that separates two locations is an indicator for the potential of interaction (25). The *distance to CBD* measure is an example of this. If a set of points or locations are all potential origins or destinations, an "integral accessibility" index measures the degree of interconnection of a location i to all other locations, j:

$A_i =$, where A_i = integral accessibility and a_{ij} = relative accessibility (26). The point with the lowest accessibility index (shortest overall distance to all other points) is most accessible and also most central (27).

Relative and integral accessibility does not explicitly account for variable supply and demand characteristics within a network of travel origins and destinations. In general, there are few situations where trip origins are unlimited from a location and few destinations have unlimited capacities as trip ends. Gravity models are examples of accessibility measures that are able to account for attraction, opportunity, or capacity among points as well as distance and/or cost of travel (28). For instance; $I_{ij} = k X_i Y_j f(c_{ij})$,where interaction I_{ij} between locations i and j is assumed to depend on conditions at i and j as well as on interaction costs c_{ij}, X_i is a measure of the propensity of i to generate interaction and Y_j is a measure of the propensity of j to attract interaction. X_i and Y_j can represent production-attraction constraints, which are most frequently used in transportation planning models. Singly or doubly constrained models can be dynamic, reflecting changing supply or demand conditions of locations over time (29). Constrained models balance trip productions and attractions so that total zonal outflows and inflows are equal.

Each of these network analysis methods is available within a GIS in the form of shortest path, tours, routes, allocation, and flow operations (30). Attributes of the network as well as the distance or travel time between each location influence the level of potential interaction between two or more locations. These measurements are easily obtained in GIS packages such as ArcInfo, MGE, and TransCad, which have network analysis capabilities.

THE POTENTIAL OF GIS IN MULTIMODAL INVESTMENT ANALYSIS

Distributed Data Input and Maintenance

With the increasing spread of Internet access and utilization, data traditionally collected and disseminated from centralized locations (such as a transportation network, census data, REIS, county business patterns, and TAZ data) can instead be entered by separate agencies as inputs to the database. The model would then use the most recent data available (if desired) from these sources. The database would be designed to handle the level of data aggregation for each entity including time series data (at appropriate intervals). A graphical (web-based) approach would allow for spatially indexed data entry as a user interface (map-based rather than non-graphical database). Another type of data that could be captured automatically would be network volume information, such as congestion levels, queuing times, accidents, transfer delays, and road (link) conditions. This data could also be collected and maintained at appropriate time increments based upon modeling requirements.

GENERAL DATABASE REQUIREMENTS

To adequately model the various interactions between transportation activities, both on the supply and demand sides, attention is given to trip production factors for passengers, for manufactured goods, and for agricultural transportation needs. Table 2 lists these types of demands, trip production factors and specific independent variables. For example, household income and car ownership may influence passenger demand. Similarly, transportation demands for manufactured goods will vary by the commodity (i.e., Standard Industrial Classification) and value. As the different transportation demands and related factors are determined, the available data describing them will be organized along the lines of Table 2, a display which will enable users to identify gaps in data sources or inconsistencies in format (e.g., output grouped by SMSA instead of county).

The concept of distributed processing has inherent implications for inter- as well as intra-organizational data management. Several issues arise when considering a framework for data exchange among organizations. These issues tend to revolve around security, propriety, cost recovery, and maintenance (31). The reluctance to distributed processing is also a function of the lack of experience that organizations have operating in such an environment. This is not surprising considering that network technologies, especially for desktop computing, have only been widely implemented in the past ten years. On the other hand, Internet connectivity has been experiencing exponential growth over just the past five years. Distributed processing in the form of relational database management and open database connectivity (ODBC), coupled with graphical internet access (WWW) and web-based application programming (JAVA) is opening up vast possibilities as well as challenges to organizational data management.

Internet-Based GIS

The Internet has become an efficient means to share geographic data. The World Wide Web (WWW) with graphic capabilities, along with file transfer (i.e., FTP), and web application programming (such as JAVA and ActiveX controls) are bringing GIS functionality to the Internet (32). The current limitations of internet GIS are that: a) HTML documents use graphic images (such as gif and jpeg) and are not object-based with topologic data structures, b) maps can only be associated with other text and images through hypertext links, and c) users cannot edit map contents but only manipulate the view of the map (zooming, panning, etc.) (32). Basic operations like geographic queries, buffering, and overlay analysis techniques are not widely available on internet GIS, however, given the current rate of innovation in web-based GIS, it is likely that true interactivity will be available in the very near future.

Examples of Internet mapping are currently being produced with ESRI software. Objects (locations) can be queried by selected parameters. Maps can be panned and zoomed to display desired locations. An example mapping web site can be seen at: http://gis.ci.ontario.ca.us/gis/index.htm (City of Ontario, CA) and http://tiger.census.gov/ (U.S. Bureau of the Census).

CONSIDERATIONS

Geographic Aggregation

The concept of multiple contributors to a common textual database is not technologically challenging. On the other hand, a shared geographic database with data being entered and maintained with different spatial units from different organizations (such as zip codes for business activity, counties for agricultural productivity, census tracts for population and housing data, and municipal boundaries for property taxation rates) calls for either standardization of spatial units or a spatial structure that relates incongruous data reporting boundaries. In addition, point data will also need to be appropriately aggregated for location specific activities.

Preserving organizationally based boundaries for data reporting and analysis means that algorithms for relating layers of polygon data with non-common boundaries will rely on buffering, data aggregation and disaggregation routines. An example is relating population changes for a census tract and changes in business activity for a zip code to a node in the transportation network. It is likely that the zip code contains many census tracts, thus a share of business activity will need to be allocated to a census tract because it only represents a portion of the total zip code area (see Figure 6).

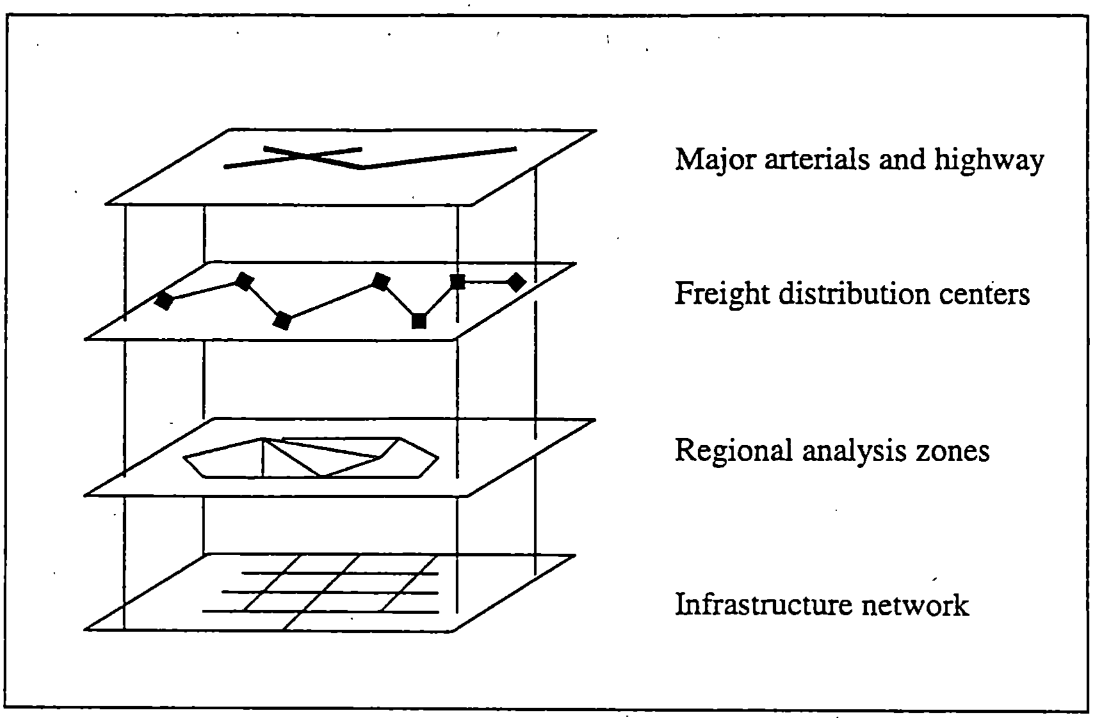
TABLE 2 Examples of Database Information Needs

Submodel	Database	Fields	SpatialUnit	Time Basis	GIS Feature Type
Passenger Demand	Trip production	Household income	Tract, city, county	Current	Area
		Car ownership	---	--	---
		Household size	---	---	---
		Occupation	---	---	---
		Population density	---	---	---
	Trip attraction	Business type:	Parcel, tract	Current	Area
		Industrial	---	---	---
		Commercial	---	---	---
		Services	---	---	---
		Employment density	---	---	---
Ag. Transport	Production estimates	Crop production:	County	Annual	Area
		Soybean	---	---	---
		Oat	---	---	---
	State livestock	Livestock production:	State	Quarterly	Area
		Cattle	---	---	---
		Poultry	---	---	---
		Pork	---	---	---
	County livestock	Livestock production:	County	5-year	Area
		Cattle	---	---	---
		Poultry	---	---	---
		Pork	---	---	---
Transfer points	Grain elevators	Capacity	Site	Annual	Point
		Services available	---	---	---
		Turnover rate	---	---	---
		Costs	---	---	---
Processors	Process type	Capacity	Site	Annual	Point
		Services available	---	---	---
		Turnover rate	---	---	---
		Costs	---	---	---
Production inputs	Supplier type	Capacity	Site	Annual	Point
		Services available	---	---	---
		Turnover rate	---	---	---
		Costs	---	---	---
Manufacturing	County Business Patterns	Employment	County	Annual	Area
		Payroll	---	---	---
		Production	---	---	---
	State-to-state commodity flows	Destinations	State	5-Year	Area
		Origins	---	---	---
		Value of shipments	---	---	---
		Commodity class	---	---	---

In this case there are the following alternatives:

1. Disaggregate to tract level on a proportional area basis
2. Assign data directly from zip code to tract
3. Aggregate tract data to zip code and use the larger area for data analysis
4. Overlay a uniform grid over spatial units and disaggregate to these units for analysis purposes

The research on constructing traffic analysis zone boundaries addresses many of these issues. Typically, different types of geographic data from different data sources will have non-corresponding levels of aggregation. The aggregation or disaggregation techniques mentioned above can be used to achieve common areal units from different geographic data types.



Source: Adapted from Prastacos (1991)

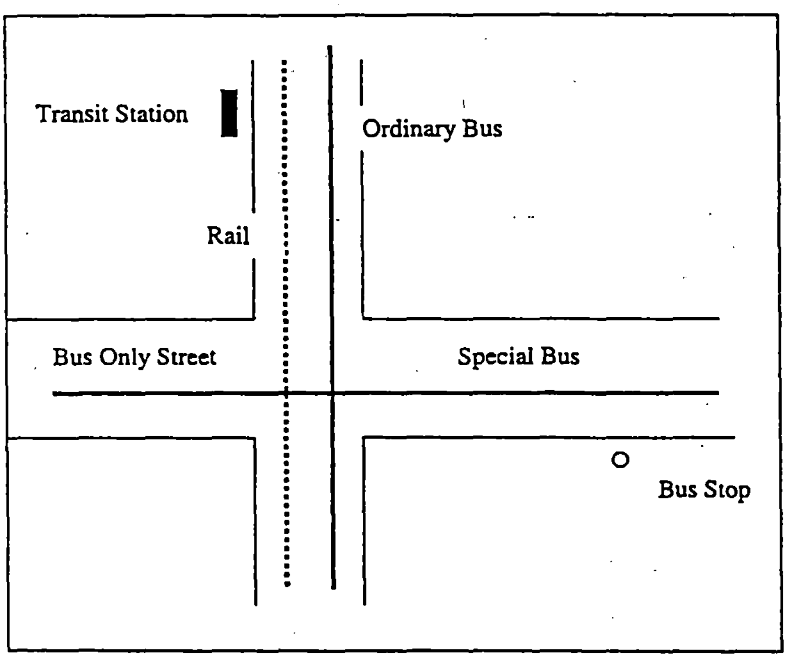
FIGURE 6 Layers of a GIS Database for Transportation Planning

Time Series/Intervals

Similar to spatial aggregation issues, it is also important to consider that a shared GIS database will involve different levels of "temporal aggregation." Currently, model inputs such as population, business activity, and agricultural production are not only reported at different spatial units, but also at different time intervals. Decennial releases of population and housing characteristics do not correspond with the census of agriculture data. Highway trip count data is not always available on an annual basis to correspond with other annually released data. With the inclusion of real time congestion and transport activity data in a distributed database structure, common time increments for data storage or modeling purposes will need to be defined. Just as with spatially incongruous data, aggregation and disaggregation methods can be used to produce comparable temporal units such as months, quarters, and years.

Insufficient Network Topology

In transportation modeling, networks tend to be simplified in order to reduce the amount of data that needs to be maintained (33). Generalizing a transportation network usually results in the representation of major arterials and highways, which carry the greatest proportion of daily trips. For inter-city transportation modeling of a single mode this is not problematic. A highway network has a relatively simple topologic structure. However, when multiple modes are being analyzed, especially when transfers or connections are not possible at certain intersection points, more data must be captured to account for these characteristics. Depending on the level of detail required by a modeling effort, a realistic transportation network will also need to represent turn (transfer) inhibitions and penalties, bridges, underpasses, overpasses, one-way restrictions, and weight (vehicle type) restrictions (34). Figure 7 gives an example of some multimodal network topology issues in an urban context.



Source: Sutton (1996).

FIGURE 7 Transit Network Connectivity

Relationship of Data Layers

One capability that is currently lacking in the GIS/transportation modeling environment is the dynamic link between layers of spatial data. There is no interaction between layers of transport facility (links or nodes) or demand (people or freight) data on an automated or dynamic basis. Demand characteristics have to be mechanically transferred to nodes before analyses can be performed. Likewise, projected trip activities from a node are not converted into areal impacts for population and employment changes. This problem is referred to as "cross-layer referencing" - not only between nodes (points) and polygons, but also links (lines) and polygons, or polygons and polygons (35). For instance, a change in population levels for a region may be a function of employment in a region - one data layer should interact with the other to show this relationship. This is typically done by using centroids, however, there is still the missing dynamic link between centroids on separate layers. This dynamic link could be established if attribute data (fields) could actually be a spatial analysis function such as a buffer with aggregation. A dynamic link between objects should also be established based upon specified distance criteria. In any event, real time, a continually updated spatial relationship, would aid the modeling process.

Legal, Economic, Access Issues for Data Sharing

Along with the exchange and sharing of geographic data a variety of legal, economic, and access issues arise. These issues act as hurdles to public and private organizations in the process of coordinating data collection and management activities. Without universally accepted accuracy standards, businesses or public agencies may be liable for distributing inaccurate data, which leads to safety hazards or economic loss. Unreliable geographic data used for technical purposes (e.g. navigation and civil engineering) may lead to hazardous situations.

Economic considerations almost certainly arise in relation to data sharing activities (36). Geographic data collection and management are expensive to support. How should costs be shared? Should the original provider of the data absorb all of the costs, assuming that he will be the beneficiary of other data collection efforts for which they did not pay? In a data-sharing environment, how can cost sharing be structured equitably? Because there are profit-making opportunities connected to the use of geographic data, the potential for "free-riders" is high. This also relates to the issue of data access. How will data access be controlled among cooperating organizations? Will there be a hierarchy of access levels based upon pricing or confidentiality? Controlling data access becomes a very complicated issue considering the potential for improprieties of data handling and dissemination.

More specifically there are potential problems with allowing public access to government databases. When electronic data is made available to the public there is the potential for accidental for deliberate destruction, loss, alteration, or degradation of data (37). In addition, the release of "secret" information regarding defense and toxic chemical locations is an example of sensitive locational data. On the other hand, the release of previously unavailable government geographic data may serve to increase the publics awareness of government sponsored activities that the public may be critical of. At this point in time the issues are primarily institutional. Technologies for data access and dissemination already exist. Large amounts of data collected by the federal government are currently being provided in CD-ROM and Internet downloadable format. Transportation, demographic, economic, and environmental data is readily available to public users.

SUMMARY

The application of GIS to multimodal investment analysis stands to make significant improvements in the areas of impact assessment and modeling. In addition to the graphic nature of GIS, the database capabilities along with spatial analysis tools provide a useful platform for regional economic modeling. The potential for distributed database management activities can result in a more functional, flexible, and accessible data structure. At the same time it presents a number of challenges to modelers to insure data integrity. The benefits of a GIS-based investment analysis system extend beyond the capabilities and analytical functions of GIS. Organizational benefits related to more efficient and effective data acquisition and maintenance can represent substantial savings and improvements to data quality.

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CHAPTER 3

CONCEPTUAL MODEL OVERVIEW

SCOPE OF THE MODEL

Intermodal Focus

The model developed for this project is intended to address transportation issues and problems on a regional or statewide scale. Consequently, the model differs in a number of respects from the models typically used for urban transportation planning. First, this model differs is that it addresses both passenger and freight transportation. Traditional urban transportation models focus on passenger transportation. However, ISTEA has placed added emphasis on freight transportation recognizing the need for improved efficiency in the movement of natural resource, agricultural and manufactured goods in order for the United States to remain a leader in the international marketplace. Therefore, this model addresses the location, accessibility and scale of freight transfer facilities; conflicts between freight and passenger facilities; and the shared use of transportation facilities by freight and passenger traffic.

Ownership Alternatives

The second way this model differs is that it addresses both public and privately owned transportation infrastructures. The redirection of federal transportation programs from a modal to a system-wide focus requires increased cooperation and coordination between the public and private sectors. Coordination is especially important when addressing intermodal transportation needs. Continuing to focus transportation planning on just public facilities would result in a suboptimal transportation system.

Logistics Issues

The model also addresses logistical issues, such as distribution and production facility location. Although the relationship between business logistics and transportation planning is well recognized, transportation planners have generally taken the location of such facilities as exogenous variables to which transportation systems must respond. However, in reality decisions made regarding transportation system and logistic facility investment are often made simultaneously.

Economic Feasibility and Impact Analysis

Fourth, the model integrates economic feasibility and economic impact analysis with the analysis of issues traditionally addressed by transportation models, such as traffic congestion and air quality. Traditional transportation models include information on levels of economic activity, such as population, employment, personal income, and trade flows, as exogenous factors used to estimate trip productions and attractions. Feedback effects to an area's economy resulting from transportation investment are generally ignored. In addition, economic feedback effects are generally omitted in analyzing the economic feasibility of transportation investment projects. The rationale for the exclusion of these effects is the view that they represent transfers of economic activity and do not result in net changes in the overall level of economic activity. This view is only partly correct. To the extent that transportation improvements result in gains in productivity beyond those measured as travel time-savings and vehicle operating cost savings, they should be included in the feasibility analysis for transportation investments. Also, transportation system improvements may accelerate the rate of growth of economic activity in an area. Given that the value of benefits and costs associated with a project decrease with time, a project accelerating the realization of benefits enhances the economic well being of society.

Distribution of Impacts

Finally, the model quantifies the distribution of impacts among different segments of society and among different business sectors. Although not important from the perspective of a project's economic feasibility, disaggregation of benefits and costs among various constituencies becomes important in building political support for a transportation system improvement. Also, this feature of the analysis becomes essential in allocating financial responsibility and for devising financing mechanisms for a project. In particular, this aspect of the model is required in order to identify the extent to which transportation investment may be financed employing market pricing versus public subsidy.

Thus, this model internalizes many factors that are omitted from traditional transportation models. In this manner the model permits the dynamic analysis of transportation system investment alternatives.

MODEL STRUCTURE

The model incorporates many elements of the traditional four stage urban transportation modeling process. However, this process has been modified and expanded in six major respects. First, the model is demand driven meaning no *a priori* assumptions are made regarding the options available for solving a particular transportation system problem. Second, the trip generation and distribution stages have been disaggregated to more accurately capture the unique transportation service demands of intercity passenger, natural resource and agricultural commodity, and manufactured goods traffic. Third, the mode choice analysis incorporates a series of filters associated with trip purpose and population characteristics for passenger service demands, and product and market attributes for freight service demands. Fourth, the model addresses the traffic impacts of transfer, distribution and production facility location decisions as well as transportation way and terminal facility investment decisions. Fifth, the economic effects resulting from alternative transportation and logistic system investments feed back into both the trip generation and traffic assignment stages of the model. Sixth, the transportation network and regional economy components of the model are supported by a single geographically referenced database. A more detailed description of the distinguishing features of the model is provided below.

Transportation Demand Forecasts

The demand for all transportation services is derived from personal needs or business practices for passenger trips and from market forces or logistics requirements in the case of freight movement. There exists an obvious distinction between factors from which the demands for passenger and freight transportation service are derived. Furthermore, even within these two broad categories, factors influencing transportation needs differ enough to require a variety of approaches to adequately estimate and forecast these demands for service.

For example, individuals demand intercity transportation services for a variety of economic and personal reasons. Economic reasons for intercity passenger travel include employment, delivery of business services, marketing and product promotion, training, and meeting and conference attendance. On the other hand, personal reasons for intercity travel include recreation, vacation, shopping, medical and other professional services, family obligations, and education.

The demand for freight transportation service depends to a great extent on a product's stage in the production process. Transportation service demands for intermediate goods are often dictated by the logistics requirements of industries for which they are inputs. On the other hand, transportation service demands for both raw materials and finished goods are generally market-driven.

Recognizing these differences in the factors that influence the demands for intercity passenger and freight transportation services, the model disaggregates the trip generation and distribution stages into five components. For passenger service demands there are separate model components for business and non-business travel. For freight transportation, service demands for raw materials (i.e., agricultural and mineral), intermediate goods, and finished goods are each modeled separately.

Delineation of Passenger and Freight Service Requirements

In addition to the demands for transportation service depending on the different purposes identified in the previous section, individuals and business managers respond to a variety of preferences and service requirements when determining the types of transportation service that most appropriately meet their needs. For passenger transportation, factors such as the values placed on time, convenience, comfort, and security, as well as out-of-pocket cost, influence travel choices in terms of time of travel, mode choice, and route. For freight transportation, the physical characteristics of a shipment (i.e., size, weight, and density), the physical state of a shipment (i.e., gas, liquid, or solid), product perishability, and value similarly influence travel choices. Also, market options and logistics management practices, such as the growth of international trade, the increased use of shipping containers, and the adoption of just-in-time inventory management, strongly influence transportation service requirements.

These passenger and freight service preferences and requirements are incorporated in the model in the form of general service characteristic filters. The filters provide a basis for classifying transportation service demands according to common basic attributes, such as travel time sensitivity, special handling requirements, value of service, and physical attributes. These filters, combined with modal service characteristics described in the next subsection, act to limit the universe of viable transportation system improvement options.

Delineation of Transportation Mode Service Characteristics

The service characteristics of transportation modes vary in terms of accessibility, capability, reliability, security, speed, energy efficiency, and cost. No single mode possesses a clear-cut advantage in terms of all the service characteristics. For example, motor vehicles possess a clear advantage in terms of accessibility in providing either passenger or freight service, but they are not as efficient as barge or railroad in hauling bulk commodities like coal. Similarly, air transportation is generally the fastest of all modes for trips over a few hundred miles, but it suffers severe limitations in terms of shipment size constraints and cost.

Given the multi-modal scope of the model, every effort is made not to prematurely limit modal options for meeting transportation service needs. However, some options are clearly not viable for satisfying special types of transportation service demands. Consequently, the model employs a set of modal filters to identify the technologically feasible options for each category of transportation service demand. For example, pipeline in all cases and barge in most cases would be eliminated at this stage in the model as options for passenger transportation. Similarly, motor carrier and railroad options would be determined non-viable for long distance movements of large volumes of natural gas.

Mode Choice and Route Assignment Analysis

The objective of this component of the model is to determine the pattern of mode and route choices that optimize the operating performance of the transportation system. The exact form of the optimization rule varies among the different transportation service demands.

For passenger transportation the mode choice and route selection decisions are generally made sequentially. Trips made for personal reasons are disaggregated by trip purpose and trip characteristics, such as distance, time of day, and number of individuals making the trip. Trip purposes and characteristics interact to define the traveler's choice of modes. Then, with the mode choice decision made, the route followed in making the trip is determined to minimize one's travel time.

Passenger travel for business purposes is similarly influenced by the purpose for which the trip is being made and by the trip characteristics. In some cases the trip purpose precisely determines the mode choice, such as is the case for trips associated with the delivery of many business services which require a motor vehicle to carry service equipment and supplies. When mode is not predetermined by the trip purpose, mode and route choices are usually made to jointly minimize travel time and out-of-pocket cost.

For bulk natural resource and agricultural commodities, modal and routing decisions are generally made simultaneously. In the case of agricultural commodities, such as corn and soybeans, trip destinations are determined in accordance with the producer's or marketer's desire to maximize income net of transportation and handling costs. Thus, modal and route options are considered simultaneously with market bid prices in determining the optimal distribution pattern for these commodities.

In the case of intermediate manufactured goods, mode and route choices are more constrained than for bulk commodities. Also, often either the producer or the purchaser of the product determines the transportation mode while the carrier chosen to provide the transportation service determines the route. In addition, trip destinations are generally predetermined by contractual arrangements between producers and consumers of the intermediate goods. Although transportation rates may influence these contractual arrangements, other factors such as technical features of the product, product quality, reliability of the suppliers, and volume price discounts play a more important role in the establishment of these supplier-customer relationships.

For finished goods the choice of transportation mode and route are generally made sequentially. First, either the manufacturer or the purchaser of the product decides on the mode of transportation. This decision generally reflects the desire of the party making the mode and carrier choices to minimize overall logistics costs. Then the carrier chosen to provide the transportation service determines the routing in order to minimize its operating costs.

System Capacity Needs Evaluation

The initial process of estimating the demands for transportation service, distributing trips among alternative origins and destination, choosing transportation modes, and assigning traffic to specific routes results in the identification of capacity constraints on the existing transportation and logistics system. This stage of the analysis involves the quantification of the magnitude of these system deficiencies.

The principal focus of this stage is the extent to which congestion on the existing transportation system results in the diversion of traffic among routes, modes, and time periods from what they would be under optimal conditions. The impacts of traffic diversion are measured in terms of changes in travel time and vehicle operating costs. Safety impacts are also quantified.

In addition logistics system constraints involving the location, size, and layout of storage, distribution and transfer facilities are evaluated. The costs associated with capacity constraints involving these types of facilities are measured in terms of changes in inventory costs, delay time, operating costs, and capital costs.

Project Alternative Identification and Evaluation

The initial four-step transportation service demand analysis results in the identification of existing transportation and logistics system utilization. This stage of the analysis results in the identification of what usage of the transportation and logistics system would be under ideal conditions. The differences between the two scenarios provide a set of potential system improvements. Conceivably, more than one alternative exists for solving system capacity problems. In other cases a combination of system improvements are required to solve capacity problems. Often improvement alternatives involve two or more transportation modes, as well as changes to logistics facilities.

The evaluation of improvement alternatives requires the quantification of costs and benefits associated with each. How costs and benefits vary depending on the timing or phasing of alternative improvements must also be taken into consideration. To the extent possible externalities arising from different alternatives must also be included in the analysis. In addition, non-quantifiable impacts should be described. Because different alternatives may be expected to impact the economy of the area under study, feedback effects from the economy to the transportation and logistical system may be expected. Consequently, several iterations of this stage of the analysis may be required.

Economic Impact Analysis and Feedback Evaluation

Improvement to an area's transportation and logistics infrastructure may be expected to give rise to associated productivity gains and/or expanded market opportunities for the area's businesses. Transportation system improvements may also make an area more attractive as a place for people to live and for recreation activities. These impacts of infrastructure investment on an area's economy may in turn be expected to influence how the infrastructure will be used.

For example, if improvements to the transportation system make an area's manufacturing enterprises more productive than similar businesses located elsewhere, then manufacturing activity may be expected to increase in the area. The resulting impacts on the demand for transportation services that may be expected to follow include increased levels of freight movement, changes in supply sources and markets, increased demand for warehouse space, and more and possibly longer trips by people commuting to work. In this sense the initial transportation and logistics system improvements may be expected to have a multiplier effect on both the area's economy and on the demand for transportation services in the area.

Furthermore, the stimulation of an area's economy resulting from transportation and logistics system infrastructure improvements may affect the character of transportation service demands. For example, as an area's economy grows it generally diversifies. Thus, an area's economy once dominated by agricultural and manufacturing enterprises may experience substantial growth in the service and retail sectors. When this occurs, demand for commercial air transportation for both passengers and express freight may follow.

Thus, improvements required to remedy initial system deficiencies might be expected to result both increased demands for service and changes in the types of transportation and logistics service demands. Recognition of these secondary, or induced, impacts requires the model incorporate the analysis of how system improvements impact an area's economy and then how changes in an area's economy feedback additional service demand requirements to the transportation and logistics system.

Investment Feasibility and Impact Distribution Analysis

The evaluation of investment feasibility for public sector transportation system improvements generally involves conducting a benefit-cost analysis. Traditional types of benefits taken into consideration include:

- the value of travel time savings
- the reduction in vehicle operating costs
- savings associated with improved safety
- the value of beneficial and adverse environmental impacts

Other types of economic benefits are generally ignored. The rationale for ignoring other types of benefits, such as changes in personal or business income, is the belief these represent transfers of economic activity or they represent just another way of quantifying the four types of benefits previously identified.

Care needs to be taken to avoid the double counting of benefits; some of the economic impacts of transportation system investment fall into this category. For example, increases in land values near a relocated highway in many cases represent nothing more than the value lost by property located near the previous highway route. Similarly, a business's increased profits resulting from a decrease in transportation costs associated with shipping its products to market often represents little more than another way of counting travel time, operating cost, and safety cost savings resulting from the transportation system improvement.

On the other hand, many types of benefits experienced by individuals and private businesses resulting from transportation system improvements represent a net gain to society over and above the value of the transportation and environmental impacts previously mentioned. For example, transportation system improvements that improve the reliability of goods movements may result in a reduction in inventory requirements and distribution center locations. Also, transportation system improvements may result in an expansion of market opportunities. This may permit a firm to adopt more efficient technology than would be justified by the smaller market area previously served. In addition, expanded market access may mean a broader selection of merchandise for consumers. Furthermore, transportation system improvements often result in expanded employment opportunities that permit individuals to make better use of their training and skills.

On the cost side of the equation, businesses only take into consideration their own private costs when evaluating investment options. Thus, the evaluation of all transportation and logistics system improvement options within a single benefit-cost framework provides a more accurate assessment than do separate evaluations of public sector transportation improvements and private sector transportation and logistics system improvements. Similarly, using a single social discount rate rather than separate rates for public and private sector improvements yields a consistent basis for comparison of different packages of improvement options that include both public and private sector elements.

Furthermore, the comprehensive evaluation of both public and private sector improvement options is required in order to permit the determination of how benefits and costs are distributed among different social and economic segments of society. The identification of the extent different constituencies benefit from alternative transportation and logistics system improvements serves two needs. First, no improvement is generally favored by everyone, and often improvement options benefit some groups while penalizing others. Consequently, the identification of beneficiaries is needed in order to be able to identify the political feasibility and fairness of different improvement options. Second, the distributional analysis may be used to provide a basis for devising financing plans for the different options. In some cases this may require some groups of beneficiaries (winners) to subsidize other groups (losers) in order to win support for a particular system improvement.

As outlined above, a multimodal investment model must be both comprehensive and integrated. It must be comprehensive in the sense that the entire transportation and logistics system of an area under study is taken into consideration. This means that all modes of transportation, whether under public or private ownership, be incorporated in the model. Also, the incorporation of logistics facilities is required because decisions made regarding the investment in transportation facilities often impacts decisions regarding the location and scale of logistics facilities, and vice versa.

In addition, to facilitate the consideration of feedback effects resulting from transportation and logistics system improvements, the model must integrate traffic analysis and economic impact analysis capabilities. Finally, given the spatial and temporal nature of the types of issues the model is required to address, the integration of the traffic and economic impact analysis capabilities requires the support of geographic based data structure. This data structure is discussed in the next section.

GEOGRAPHIC DATABASE AND MODEL INTEGRATION

The demand for transportation services and the economic impacts that result from transportation and logistics system improvements possess both spatial and temporal dimensions. Consequently, a geographically referenced database is required to support the multimodal investment analysis model. The accommodation of transportation system analysis and economic impact analysis within a geographic information system (GIS) presents a number of challenges. However, this approach also possesses numerous advantages over traditional modeling methods. The requirements and advantages associated with the development of such an integrated model are discussed below.

Integration of Transportation and GIS Modeling Capabilities

The integration of transportation system analysis software with a GIS database requires the combination of point, line and area feature and attribute files in a single database. Point files represent features of the transportation and logistics system (i.e., access, junction and interchange points, traffic zone centroids, and logistics facility locations) and location references for demographic and economic data used to forecast transportation service demands. Line files represent transportation guideway features (i.e., highways, rail lines, pipelines, and waterways), and area files include political jurisdictions, traffic zones, and environmental features.

The combination of transportation and logistics system information with demographic and economic data in a single geographically referenced database has four advantages. First, data used to forecast the demand for transportation service is generally not collected on a geographic basis consistent with traffic zone boundaries. The use of GIS makes the reaggregation of data relatively easy. Second, the analysis of different transportation and logistics system improvements often requires the reconfiguration of traffic zones, the resegmentation of guideway elements, and/or the addition or subtraction of access, interchange or junction points. These system changes generally necessitate the re-estimation of service demands. The flexibility inherent in GIS permits the accommodation of a much broader set of improvement options than do conventional transportation network models. Third, transportation system improvements often affect an area's economy, which in turn results in additional and different demands for transportation and logistics services. The integration of the transportation system model with GIS permits the identification of these feedback effects by making the adjustment of demographic and economic data simultaneous with the determination of transportation and logistics system service demands. Fourth, the spatial analysis capabilities of GIS support the analysis of the geographic distribution of transportation and logistics system improvement impacts on the environment, land use patterns, and population groups.

However, in order for transportation and logistics system analysis to be carried out within a GIS several requirements must be satisfied. First, the transportation elements of the GIS database must be configured as a connected network rather than just as cartographic elements. Second, the GIS must accommodate the dynamic segmentation of system elements. Third, the transportation network must be geographically referenced in a manner consistent with the demographic, economic, and environmental coverage. Fourth, the GIS must accommodate the offsetting of coincident transportation system elements, such as parallel highway and rail lines, for display purposes, while maintaining true location references for traffic modeling. Fifth, changes to the system, including traffic zone adjustments, must be automatically reflected in associated attribute data files.

Integration of Economic Impact Analysis and GIS Modeling Capabilities

The incorporation of economic impact analysis capability within a GIS requires both the spatial and temporal referencing of demographic and economic data. Economic impact models generally consist of five elements:

1. A population and labor supply element
2. A wage, price and income element
3. A consumption, government expenditure and trade element
4. A labor demand and capital investment element
5. A business input-output element

Integration of economic impact analysis capability with a transportation and logistics system augmented GIS requires the incorporation of a sixth element, i.e. a trade flows element. This sixth element allows the estimation of levels of economic interaction among different regions. In addition, it provides the capability to convert economic activity measured in dollar terms into weight units and transportation vehicle counts.

The principal advantage of integrating an economic impact analysis capability into the model is the facilitation of the identification and estimation of feedback effects resulting from alternative transportation and logistics system improvements. Conventional transportation system models permit the identification of the extent to which system improvements redistribute existing traffic among elements of the system and the extent to which new traffic is induced by satisfying previously existing latent demands for transportation service. The economic impact capability adds to this newly generated traffic arising from demands for transportation and logistic services resulting from economic growth that would not occur in the absence of system improvements.

Integration of Investment Feasibility Analysis and GIS Modeling Capabilities

The feasibility of public sector infrastructure investment projects is generally evaluated using benefit-cost analysis. The primary differences between this method of investment analysis and the methods used for private sector projects are (1) a societal versus firm perspective, (2) the internalization of externalities, and (3) use of a social discount rate. In addition, public sector investment analyses are increasingly being required to identify the distribution of benefits and costs as well as aggregate measures of project feasibility. These impact distribution analyses often possess a geographic dimension.

For transportation and logistics system projects the geographic distribution of impacts on an area's population and economy may be significant. Improvements in accessibility for one area resulting from transportation system investment often result in the transfer of economic activity from one location to another. Also, location of an improvement often has a direct bearing on the cost of the project. Thirdly, social and environmental impacts typically vary by location. Thus, conducting economic feasibility analysis within a GIS environment greatly enhances the quality and content of project evaluations.

CHAPTER 4

DATABASE MODEL

NATIONAL AND REGIONAL ECONOMIES DATABASE

Model Structure and Information Requirements

Transportation data is unique because, as Morgenstern (1, p. 44) notes, "When objects to be accounted for are moving about considerably, it may be impossible to obtain a desired precision." A survey of users of freight transportation data showed that academics most frequently used intercity tons by mode, rail car and TOFC loadings, and rail ton-miles. Consultants used rail car and TOFC loadings, followed by rail ton-miles, and then intercity tons by mode. Consultants viewed the carloadings data as more accurate than the intercity ton-miles reported for various modes (2, pp. 71-74).

Data Sources

Foremost among transportation data sources has been the work of Smith, whose *Transportation Facts and Trends* has been continued by Wilson as *Transportation in America* (*TIA*). This set of data tables is an annual publication with quarterly updates, and includes both macroeconomic data and more detailed information. For example, transportation's share of the GNP was 16.3 percent in 1996, down from 17.2 percent ten years prior (3, p. 4). *TIA* provides some basic analysis of the data collected. Bar and pie charts display financial information, such as revenues of intercity carriers and petroleum consumption by mode, while line graphs show trends in trailers and containers purchased and ships built in the U.S.

National economic measures reported by *TIA* include GNP, population, intercity ton-miles and passenger-miles. Modal data includes amounts spent for carrying freight by highways, in categories of intercity and local truck, and intercity bus. Rail revenues are grouped into one statistic, while water is segmented into international, coastal/intercoastal, inland waterways, Great Lakes, locks and channels. Oil pipeline revenues are reported as regulated and non-regulated, and airfreight is either domestic or international. Freight forwarder costs are considered in "other carriers" and additional costs of loading, unloading and other traffic operations are included, as well (3, p. 40). Two tables of much-used data are domestic intercity tons and ton-miles by mode, with historical data (in 5 year increments) extending back to 1950 (3, pp. 44-46). Transportation of petroleum is reported by ton-miles, by mode. It is the only major industry to receive this detailed treatment (3, p. 59). Employment, numbers of vehicles, miles of intercity airways, highways, waterways, railroads and pipelines are reported, as are distances covered, by mode, in for-hire passenger trips and interstate freight.

TRANSPORTATION AND LOGISTICS NETWORK DATABASE

Traffic Zone Definition

The existing data sources are described as agglomerated over product lines and geographical boundaries. While the original data elements may have been individual shipments, described by origin and destination and by product type and amount, the reported data have been broadly grouped to obscure much potentially useful information. National data may be allocated according to some logical bases (e.g., state populations, employment by SIC) to arrive at the more useful estimates. Further allocation may be made on the basis of county size (or groups of counties), recognizing that collecting originally at the county (or smaller zone) would be more accurate, but require more resources than is generally practical. To be useful for planning purposes, i.e., to evaluate proposed transportation investments, data for smaller zones will be more valuable than national or state data.

Network Characteristics, Nodes and Links

The links and nodes for intermodal networks vary little from a single-mode network. The main difference is that the nodes need to be better defined, in terms of capacity (e.g., units or tons per hour, passengers per day). For example, bottlenecks may occur at ocean ports if ships needing unloading must wait for previous outbound traffic to be cleared

GIS Database Structure and Data Management Capabilities

An organizational scheme for transportation data was developed by Jack Faucett Associates (JFA) along four transportation system attributes: "supply, demand, performance, and impacts" (4, p. 2). Supply data describes the physical facilities (i.e., characteristics and financial condition of the service providers). Demand data describes the quantity of travel, temporal and spatial distribution, and users' behavioral characteristics. Performance data measures how the transportation systems meet the needs of the users; cost data and safety data are found in this category. Impacts data describes the effects of transportation on environmental and other societal goals (4, p. 5).

Within the supply attributes, JFA sub-divides the data into systems, service, facilities, condition, and project data, and maintains separate data files for highway, rail, transit systems, ports and inland waterways, and air. Demand attributes are organized under the headings of economic data, demographic data, land use data, commodity flow data, travel data, and travel behavior data (4, pp. 7-16).

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CHAPTER 5

PASSENGER TRANSPORTATION

INTRODUCTION

This section deals with various factors and aspects that should be taken into account in forecasting the demand for intercity passenger transport. It discusses intercity passenger travel behavior and how this affects the demand for different modes of transportation. Also, this section identifies the different trip purposes that generate intercity travel demand and the different characteristics of each trip purpose. It focuses on trip generation and distribution factors, and it formalizes the functional relationships between transportation service demand and the factors associated with each trip. These relationships provide the basis for developing models used to forecast intercity travel demands and the choice of modes of transportation.

DELINEATION OF TRIP PURPOSES

The most common trip purposes in intercity travel are journey to work, business and non-business. Non-business trips include trips made for shopping, recreation and personal business. The *journey to work* is made from a person's place of residence to place of employment, which may be a manufacturing plant, a retail store or shopping mall, or a public or private institution, such as hospital or university. The journey to work includes both the trips from home to work as well as the return trip. In the context of intercity travel, the journey to work include trips that cross municipal boundaries (i.e., commuter trips) and does not include trips within an urbanized area. *Business travel* is related to the performance of the traveler's work. Examples of business travel include: sales representatives' everyday travel like product sales and service delivery, obtaining training, travel to business meetings and conferences, travel to company's head offices and trips associated with government business.

Non-business travel includes personal travel not related to one's work. *Recreation travel* may be related to a traveler's vacation, although it could also be intended for other specific recreational activities such as attending sports events, concerts, etc. Recreation travel can be expected to exhibit elasticity characteristics that are reverse of those of business travel. The value of time and money is different for different types of trips. Business trips give priority to time, while recreation trips are dependent on the cost of the travel. *Shopping trips* are trips to any retail outlet, regardless of the size of the store and whether or not a purchase is actually made. These trips usually have more frequency than recreation travel, usually shorter distance than both recreation travel and personal business, and are made at different times of the week. The most common purpose under *personal business travel* is visiting friends and relatives, which is usually referred to as *vfr*. This could also include trips to doctors, lawyers or other special services not found locally.

IDENTIFICATION OF TRIP CHARACTERISTICS

Trip characteristics influence mode choice. The most important characteristics that influence mode choice are the length of the journey and the trip purpose. Other important trip characteristics that affect mode choice includes frequency of the travel, number of people making the trip, seasonal variation, and the amount of baggage carried on the trip.

Trip Length

The demands for intercity travel over different trip lengths exhibit fundamentally different characteristics. They have different elasticities to their various determinants and follow different temporal patterns. Consequently, the stratification of trip length is an essential disaggregation in intercity demand analysis. In intercity transportation analysis two types of travel are distinguished, long haul and short haul. A distance criterion of one thousand kilometers (approximately 620 miles) is used to distinguish between long haul and short haul trips. But this is not a fixed threshold and depends on the characteristics of the transportation system available.

Long haul travel is usually less elastic with respect to the attributes of the transportation system than is short haul travel. One reason is the limited extent of choice in long haul travel. This is because, as the trip length increases, the number of alternatives (modes, routes, etc.) with comparable levels of service decreases, the extent of which depends on the availability of transportation systems and the geographic nature of the region. Long haul travel is not very sensitive to transportation attributes such as schedule frequency and modal access and egress times because the travel time is usually so large that the variations brought about by changes in these attributes are not very determining. When dealing with long haul traffic in the agggregate sense, it is usually sufficient to treat *business travel* on an annual basis and *non-business travel* on a seasonal basis.

Short haul travel often involves a priority choice of mode and a choice of route available to the traveler. In addition, the travel time is usually sufficiently small so those attributes such as frequency and access characteristics become important determinants. The analysis of short haul travel demand is almost like that for urban travel. Short haul trips are made with greater frequency than are long haul trips and exhibit weekly, and sometimes even daily, temporal patterns. In this case analysis on an annual basis will not be sufficient. In many intercity corridors where commuting work trips are made or where multi-modal transportation networks are so ubiquitous that a mode choice situation arises that is similar to urban travel and urban models are used (1). Table 3 displays mode choice percentages for mid-west business travelers, showing also the ranges of distance traveled (by respondents to the Bureau of Transportation Statistics survey). Automobile was selected by 76 percent of travelers, and highway travel, in general, is clearly dominant when rentals and truck transportation (and bus, included in "other") are added.

TABLE 3 Distance Traveled and Mode Choice for Business Travel in the Mid-West

Distance (Miles)	Mode	Percent of Total
68-1251	Car	62.6
15-4722	Truck/Rental	28.9
12-2750	Commercial Plane	6.9
91-1994	Rail	0.1
76-2146	Other	1.5

Source: 1995 American Travel Survey, Bureau of Transportation Statistics

Trip Purpose Characteristics

Trips may be compared by their elasticities of income of the traveler, cost of the trip, travel time, and by their seasonality. *Journey to work* trips can be expected to be income elastic, cost inelastic, and travel time elastic. They are temporally uniform throughout the year. *Business travel* (short haul) trips can be expected to be cost inelastic because the trip cost is usually not a personal expense but rather paid out of a corporate budget of which it is a negligible proportion. These trips are also travel-time elastic with respect to other convenience-related attributes such as schedule frequency and reliability of service. Business travel can be expected to have temporal pattern that is fairly uniform year round, except during major holidays and in situations where institutionalized vacations cause a drastic decrease in business activities during a specific period of the year. Long haul *business travel* can be expected to be not very sensitive to transportation attributes such as schedule frequency and modal access and egress times because the travel time is usually so large that the variations brought about by changes in these attributes are not very determining. This is true when dealing with business travel in the aggregate and not true when dealing with individual business travelers.

Recreation travel can be expected to be highly cost elastic, but lower time and convenience elastic than journey to work and business trips. The reason for this is that the cost of a recreation trip is usually a personal expense. Recreation trips usually exhibit strongly peaked temporal patterns with peaks during vacation seasons and special recreational events. Vacation trips are more cost inelastic than are recreation trips because transportation costs generally account for only a portion of the total vacation costs.

Personal business travel has characteristics similar to recreational travel. However, these two types of non-business travel have a distinguishing factor with regard to their elasticities. The transportation cost is normally only a proportion of the total cost of the vacation and recreational trips but is almost the total cost of a *vfr* personal business trip. *Vfr* travel can be expected to have higher transportation cost elasticities than recreation and vacation travel. On the other hand, where a choice of destination is available, a vacation traveler can conceivably change destinations if the transportation cost to one increases, flexibility the *vfr* traveler does not have. This would have the opposite effect on elasticities. The extent to which these two effects cancel out depends on the availability and practicality of destination choice. This also determines whether the combination of the two trip purposes, i.e., *vfr* travel and vacation or recreation travel, can be made to one common practical destination (1).

Other Trip Characteristics

Trip frequency also influences mode choice, as does trip length. A frequently visited place, like the business headquarters might be made by airplane, if it is very far and if the trip purpose is time sensitive. Again, if the destination is not so far, like a shopping plaza, an automobile will make the trip.

The size of the group traveling and income of the travelers also influence mode choice. Operating costs of a car are fixed, in terms of the number of passengers. On the other hand, the costs of traveling by a common carrier are directly related to the number of passengers. For long journeys, which require overnight stays and meals, mode choice is considerably influenced by group size. Seasons, too, influence mode choice decision. In the winter, the not-so-far places are usually traveled by a common carrier, while an automobile would reach the same destination during the summer months.

The weight and the quantity of baggage also affect mode choice. For example, a passenger from San Jose, California who has a new job in Ames, Iowa, and plans to bring all his furniture from San Jose, will consider two modes for his travel. First, he will transport his furniture through a mover, and he and other family members will come to Ames by either automobile or airplane. The amount of baggage made necessary the model choice of truck transportation in addition to the personal car or commercial airplane. (Modes, such as rail or bus, are possibilities but probably less practical for the origin and destination in this example.)

The above example may be influenced by the need for a vehicle at the destination. Assuming the family owned an automobile before the move, the need to move it to the new location may be the greatest influence in the modal choice for one or more family members. However, if they were uncertain of the car's ability to withstand the rigors of a long trip, the alternative of disposing of the car in California and replacing it at the new location, after arriving by air, becomes more likely. Business travel is often assumed to be more time-sensitive than cost-sensitive, resulting in longer distances being covered by air travel, with vehicles being rented at the destinations; the alternative would be to drive the entire trip, ensuring the availability of a vehicle at all times and avoiding higher variable costs of short-term rentals. On the other hand, if the trip purpose is recreation, even a very long trip might be taken entirely by an automobile.

Decisions about mode choice are made by passengers, taking into account these and other interrelated trip characteristics. Table 4 shows how intercity passengers rank transportation system factors of travel time, cost, frequency of schedule, reliability, convenience, flexibility, accessibility and completeness of journey. Automobiles, although ranked last in terms of travel-time and cost, were first for all the other variables.

TABLE 4 Relative Ranking of Different Modes in Terms of their Attributes

SYSTEM ATTRIBUTES	DIFFERENT MODES OF INTERCITY PASSENGER TRAVEL		
	Automobile	**Air**	**Railways**
Travel time	3	1	2
Cost	3	1	2
Schedule frequency	1	3	2
Reliability	1	2	3
Convenience	1	2	3
Flexibility	1	3	2
Accessibility/ Completeness of journey	1	3	2

INTERCITY PASSENGER SERVICE DEMAND MODEL

Trip Generation Factors

In passenger trip generation modeling there are usually two parts, personal trip productions and attractions. *Personal trip production* factors include income, car ownership, household structure, family size, land value, population density and accessibility. Consideration of income, car-ownership, household structure and family size have been usually used in trip generation studies (disaggregate approach), while the value of land and residential density are typical of zonal studies (aggregate approach). Accessibility has also been used in some studies because it offers a way to make trip generation elastic (responsive) to changes in the transport system. *Personal trip attraction factors* include indoor space available for industrial, commercial and other services, like certain professional services such as doctors and lawyers. Another factor used has been zonal employment and some studies have attempted to use an accessibility measure (2).

Approaches to Intercity Demand Analysis

Three approaches have evolved for the analysis of intercity transport demand: the multimodal approach, the abstract mode model, and the mode-specific approach (1, pp. 223-230).

Multimodal Approach

The multimodal approach recognizes that the demands for travel by different modes are related and should be analyzed simultaneously. Short haul travel, including urban corridor travel, is done by the multimodal approach. It takes into account the fact that demand for short haul intercity travel for different modes are related, and so there is need to consider the cross-elasticities of the demand by mode type. The multimodal models of intercity travel postulate that the demand for travel between a pair of cities by a particular mode is a function of the socioeconomic characteristics of the cities and of the supply attributes of that mode, plus those of all other modes available. As such, the multimodal model is a combined destination and mode choice model with an implicit assumption that these choices are made simultaneously. These types of models often suffer from collinearity problems.

Abstract Mode Model

The abstract mode model simplifies the general multimodal transport model by specifying a demand function where for each of the supply variables, the values of only two modes are present: the mode in question and the mode offering the best value of the attribute in question. The data needs would include city population, per capita income, percent of total employment that is in manufacturing, travel time by mode *m* relative to best travel time; best travel time between the cities, travel cost by mode *m* relative to best cost; and best travel cost between the cities. This approach does not account for the social and economic character of the city and other the intrinsic characteristics of the city. The theory of intrinsic characteristics postulates that the effects of the conventional demand variables on intercity travel vary with economic and social characteristics of the city and these cannot be represented adequately by quantitative variables. This observation was first made by Lansing and Suits, who calibrated two simple gravity models, one for New York and the other for Chicago (1, pp. 227-228). These models related total traffic between each of the two cities and a selected number of cities. The variables considered were population, per capita income and distance. The differences between most of the parameter values of the two models were significant. Lansing and Suits explained these differences from the qualitative knowledge of the difference of the two cities. The major difference was noticed in the distance elasticity, showing travel to decline faster with distance from Chicago than New York. This may be partly due to the geographic locations of the two cities and also the fact that Chicago is more of a regional market center whereas New York is more of a national and international center. In order to incorporate this theory of intrinsic characteristics in the conventional regression model, the error term was decomposed into two additive components: one for intrinsic characteristics and the other for random errors. They developed a generalized least-squares estimation procedure, assuming the intrinsic characteristics to be same for all modes but different for each city pair. The results showed that the generalized least-squares method produced parameter estimates that were much superior to those produced by the ordinary least-squares method. This model modification did help in improving the statistical fit, significantly but it also had drawbacks. The model can no longer be used as it is for any city pairs other than those for which it was calibrated, and the second is that even for those city pairs, the model can be used for forecasting only if it is assumed that the "intrinsic characteristics" of the cities remain constant over the forecasting period. It also cannot forecast travel on novel modes or technologies not available at the time of calibration.

Mode-Specific Approach

This approach is based on the proposition that the demands for travel by different modes are independent, or can be assumed so, and therefore can be analyzed separately. In general, long haul travel is handled with a mode-specific approach. The mode-specific analysis for long haul travel is valid when the characteristics of the transportation system are such that no significant competition is likely to exist between modes. The most important developments in mode-specific approach are those in the demand for air travel. This is not only because it is the most important mode of intercity travel but also the assumption of independence is best justified for this mode. This is true particularly in long-haul travel and in terms of travel time, where air is far superior to other modes, catering to a segment of the population for whom travel time is the most important supply attribute, and for whom other attributes such as cost (the air mode does not have an advantage here) are relatively less important.

On the other hand, travel by long haul intercity bus is much cheaper and it caters to a segment of the population whose most important supply attribute is cost; time can be sacrificed for this economy. It has been customary to analyze their travel demands separately, but only in the short run. Mode-specific models cannot be used to analyze long-range times series travel data or for long-range forecasting. It is evident from the study of the histories of modal evolution that even in long haul travel, shifts have occurred between modes (e.g., from rail transport, which peaked in the 1940s, to air) and there are long-run cross-elasticities. This approach can explain observed trip behavior better and allows for qualitative idiosyncrasies concerning mode choice that are otherwise neglected in model variables. But the assumption of that there is no competition between the various modes is limiting. It also cannot forecast travel on novel modes or technologies not available at the time of calibration.

The multimodal approach appears to be a realistic approach. In the real world, decisions regarding destination and mode choice are done simultaneously, taking into account the other modes of travel available. This approach also takes into account the socioeconomic variables of the city pairs concerned. Another aspect that needs to be included in this approach for it to be the ideal one for demand forecasting is consideration of the theory of intrinsic characteristics of cities. The data needs for this approach will be disaggregated data and sometimes might not be very easy to find and might involve complex iterations. In this age of information technology and its high pace of advancement, that should not be a major problem.

Sequential Models

Sequential models consist of aggregate and deterministic demand type models, behavioral models with a disaggregated approach, entropy models of aggregate approach and simulation models. Aggregate and deterministic demand type models calculate the trip distribution on regions normally by a gravity or intervening opportunity method. The trip production function was assumed not to be dependent on travel time, price or frequency. The unit of observation for an aggregate approach is generally a traffic zone. The gravity model states that the number of trips made between an origin and a destination is positively related to the number of trips leaving the origin and to the pull attributes of a destination but is inversely related to the distance between the origin and the destination. Two basic differences exist between an intervening opportunities model and a gravity model. In the intervening opportunities model the *in situ* characteristics of a destination are measured simply as the number of opportunities available there. The second difference is in how the effect of geographical separation between places on the number of trips made between them is conceptualized. In the gravity model, distance per se is supposed to influence the chance of a trip being made, whereas in the intervening opportunities model, the critical factor is the number of other opportunities closer to an origin than any particular destination being considered by a traveler (4). The trip mode distribution is normally a function of the *differences* in travel time or generalized cost. The assignment of flows to the network generally adopts an all or nothing approach with or without capacity constraints (5).

The unit of observation for a disaggregate model is the individual or household. In general, disaggregate models or discrete choice models postulate that the probability of individuals choosing a given option is a function of their socioeconomic characteristics and the relative attractiveness of the option. To represent the attractiveness of the alternatives the concept of *utility* is used. In order to predict if an alternative will be chosen, the value of its utility must be contrasted with those alternative options and transformed into a probability value between 0 and 1. For this a variety of mathematical transformations exist which are typically characterized as discriminant, logit and probit functions. This type of model has a disaggregated data need that is not easily satisfied. It is also based on complex calculations.

Entropy models of aggregate behavior give the same result as the gravity model. The gravity and intervening opportunities models can only be applied in situations where data have been collected on the observed distribution of trips at some point in time and on attributes of the destinations. When these data are not available, the so-called "entropy maximizing" approach is used. A system is made up of a large number of distinct elements. A full description of this system would require complete specification of its microstates. This would mean identifying each individual traveler, its origin, destination, mode, time of journey, etc. For practical purposes, a more aggregate or meso-specification might be sufficient. For example, a meso state may just specify the number of trips between each origin and each destination. In general, there will be numerous and different microstates which produce the same meso state. In a higher level of aggregation, a macrostate, the data will specify the total number of trips on particular links, or the total trips generated and attracted to each zone. Estimates about the future are usually restricted to macrostate descriptions because of the uncertainties involved in forecasting at more disaggregate levels. It is easier to forecast the population of a zone than the number of households in a particular category residing in each zone. The basis of this method is to assume (unless there is information to the contrary), all microstates are consistent with the information about macro states are equally likely to occur. This approach enforces consistency about knowledge about macro states by expressing the information as equality constraints in a mathematical program. To find out about the mesostate descriptions of the system, this system would identify those mesostates which are most likely, given the constraints about the macro states. The aim of the approach is to provide the least-biased estimate of some missing data, such as trip distribution patterns, given just partial information on these data (2, p. 162).

Simulation models consist of two connected sub-models: an economic model based on input-output tables provides the transport model with data; and the second model assigns commodity flows to the transport network. The model involves a large number of comparisons by which the consistency of different economic and physical data may be evaluated. These in turn make possible to identify obvious weaknesses in the data and to sort the more reliable sources. The model also provides a systematic procedure for generating estimates by extrapolations or interpolations to fill gaps in the data. This macroeconomic transport simulation model (METS) encompasses many functional relationships and attempts to identify a correspondingly large number of behavioral regularities. This METS model is thus less dependent on simple extrapolation of historical trends. It can produce as by-product, estimates of certain data series that might not otherwise be available and that are not estimated very easily or inexpensively. The model is a source of data estimates and also a consumer of them. Another important aspect of this model is that it contains a number of sub-models of the transport system, which can be operated independently of the larger model and at relatively low cost. This model was applied to evaluate alternative strategies for developing the Colombian economy and transportation system (6).

Transport System Models

Transport System Models are applications of economic theory to transport situations. One finds equilibrium in the transport market by setting up a supply function and a demand function and solving for equilibrium flows. Supply function factors include travel time, travel cost, travel frequency, safety and comfort. Demand function factors include population characteristics, employment characteristics, income, urbanization factor, distance, purpose and ownership of cars. The equilibrium occurs in a network affected by capacity constraints, topology and structure of the transportation system. The four-step approach known from urban transport models has been changed into a single step, and was developed for forecasting intercity passenger transport in the North-East Corridor of the United States by Kraft, McLynn, Quandt and Baumol. In the DODOTRANS system (Decision Oriented Data Organized Transport Analysis System, developed by Manheim and Ruiters) of computer models from MIT and ICES (Integrated Civil engineering Systems), these models are available as an application of systems analysis to intercity problems (5, p. 179-180).

Basic Structure and Approach of the Passenger Service Demand Model

The conceptual model for intercity passenger demand has been developed on the basis of literature review on transport modeling. This model incorporates the strengths of the existing transport models sometimes in their original form, sometimes as modified models. The conceptual model is an integration of the various models (and sub-models) encompassing the strengths of the existing models.

The conceptual model is based on the framework developed by Manheim for intercity transport (5, p. 180). The three steps of the conceptual model are : (a) estimation of passenger traffic volume between cities, (b) distribution of traffic between modes, and (c) distribution of the transport volume for mode *m*, between *n* routes of that mode between the two regions. The model has been schematically represented in Figure 8, which illustrates a general conceptual methodology of intercity passenger transport demand forecasting. Transportation is assumed to be derived demand and so the variables that are considered exogenous are income, employment and population in this passenger model.

Estimation of Passenger Traffic Volume between Cities

Estimation of the total transport volume between two regions depends on the size of population, commercial character of the cities and the distance between them. This is usually done with the help of gravity models, intervening opportunity models and entropy models. Three elements that need to be taken into account when modeling the demand for transport between cities are the number of trips generated by a place/region; the degree to which the *in situ* attributes of a particular destination attract trip makers; and the inhibiting effect of distance.

Trips generated by a place/region can be calculated by linear regression analysis or category analysis based on attributes of that place/region, as used in urban transportation. Variables used usually try to portray the different features of the place/region in question. First, the potential number of trip makers in a zone should be identified. This is done by considering the size of population and the land use pattern of the origin. Second, the degree to which a potential trip maker's characteristics affect his or her propensity actually to make a trip should be considered. This mainly depends on income, family size, car ownership, etc. The trip purpose also plays a significant role in determining the demand for transport. Lastly, the geographic accessibility of the zone to potential destinations can also affect the number of trips made.

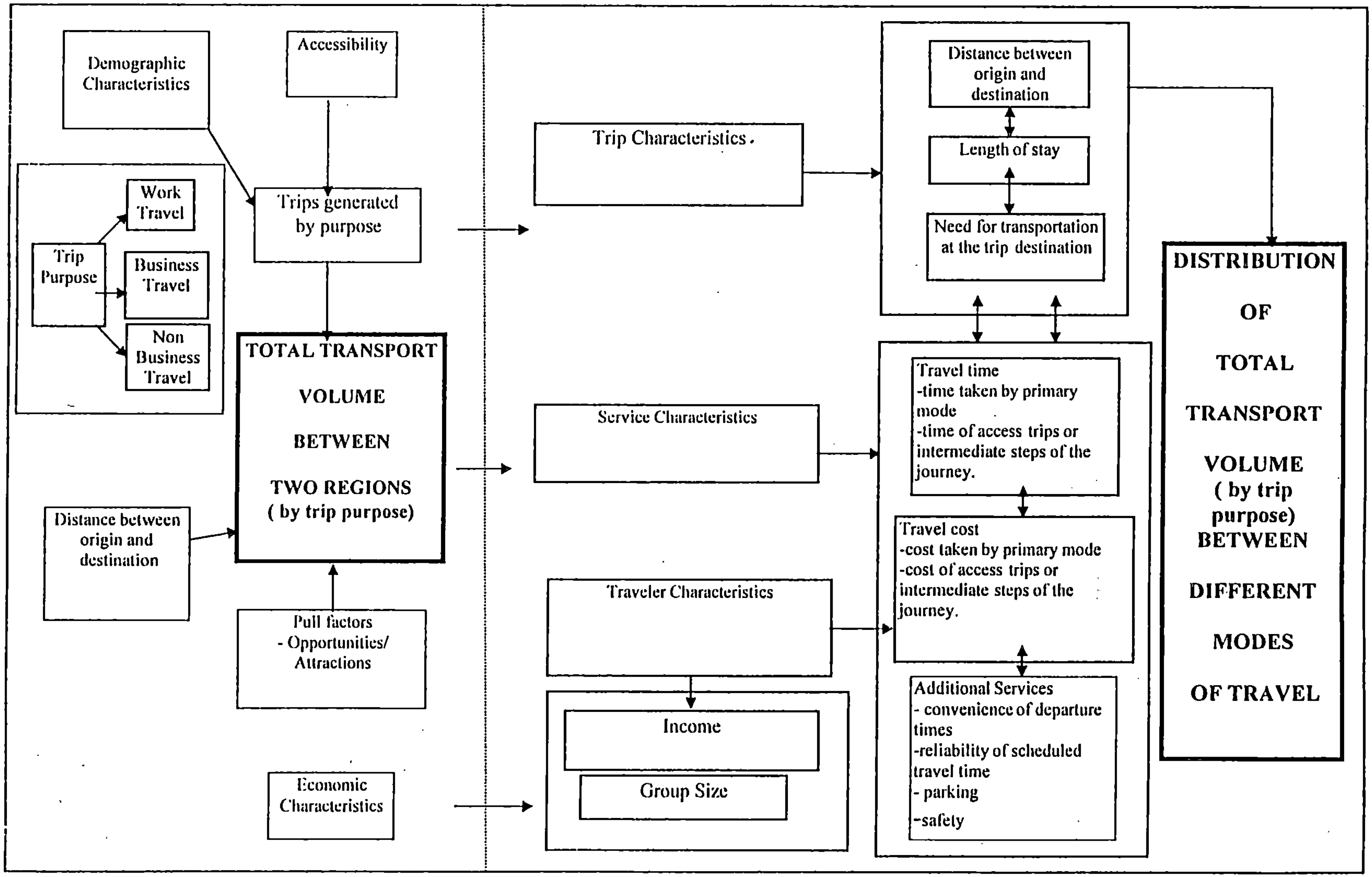

FIGURE 8 The Intercity Passenger Transportation Service Demand Methodology

The *in situ* (the theory of intrinsic characteristics) attributes of a particular place refers to the characteristics of a place to pull travelers to the opportunities offered there. The attractiveness of a place/region will vary depending on the type of trip. For example, journey to work travel will depend on the destination's employment opportunities while shopping trips and recreation travel will depend on the number of shops and entertainment opportunities, respectively.

The third element refers to how the remoteness of a destination may inhibit its ability to attract travelers, even when its in situ attributes might be favorable. In geographic terms, the second element refers to the *site* characteristics of a destination, whereas the third element refers to attributes of its *situation*. If a trip is more easily carried out because nearby places can fulfill its purpose, then that activity is relatively cheap, and an individual would be inclined to perform that activity relatively more often, other factors being equal (4, pp. 105-111). The factors influencing trip generation are tabulated in Table 5.

TABLE 5 Factors Influencing Trip Generation

Number of trip makers	**Trip-making propensity**	**Accessibility**	**Pull factors**
• Population size • Population density	• Income • Household structure • Family size • Labor force participation • Car ownership • Occupation • Percentage of non-workers	• Access to jobs	• Employment opportunities
• Land use mix of origin zone • Employment in zone by occupation	• Income • Car ownership • Type of business • Business linkages	• Intercity accessibility	• Employment opportunities • Roofed space for industrial, commercial and services
• Population density	• Household size • Car ownership • Occupation • Percentage non-workers	• Access to shopping centers • Access to leisure • Access to friends	• Shopping centers • Intervening opportunities • Other recreation opportunities

The end result of this step comes up with the total demand for transport between two regions/places, disaggregated by trip purpose. It estimates the number of person trips per unit time from origin *i* to destination *j*. The functional relationship of this step can be represented as follows:

$X^t_{ij} = (E_i E_j)/ D_{ij}$
where, X_{ij} = Total demand from origin i to destination j, at time t
E_i= Total trips generated from origin i

$E_i = A_i f\{ \alpha_i, \beta_i, \chi(r), \delta(l) \}$
where, A_i = Intrinsic qualitative factor of zone i
α_i = vector of explanatory variables for trip production by trip purpose from zone i
β_i = vector of socio-economic explanatory variables for trip production from zone i
$\chi(r)$ = vector of infrastructural explanatory variables for transportation route *r* (Access)
$\delta(l)$ = vector of infrastructural explanatory variables for network link *l* (Access)

$E_j = A_j \Phi(a_j, b_j)$
where, A_j = Intrinsic qualitative factor of zone j
a_j = vector of explanatory variables (economic) for trip attraction, to zone j
b_j = vector of explanatory variables for intervening opportunities within zone i and j
D_{ij} = Distance decay factor (distance between i and j)

Distribution of Traffic between Modes

Distribution of the total transport volume between different modes of travel depends on travel time, fare and service frequency. The choice of intercity travel mode, for both short haul and long haul travel depend on certain characteristics of the mode(s) in question and also traveler, and trip purpose characteristics. The distribution of trips with a given mode is proportional to the service frequency and inversely proportional to the fare and travel time.

Trip characteristics The length of the trip and its purpose influence mode choice more than any other trip characteristic. The length of a trip usually determines the viability of a mode and also the viability of other modes, taking into account the trip purpose and its characteristics. Business travelers generally place a greater premium on travel timesavings and have less schedule flexibility than non-business travelers. A related characteristic concerns the traveler's need for transportation at the trip destination. If an automobile is required, then using a private automobile for the intercity trip becomes relatively more attractive. The distance between the origin and destination also influence the mode choice. Length of stay will also affect the desirability of using a private automobile because rental car costs are directly related.

Service characteristics The most important service characteristics between traveler's origin and final destination are travel time and travel cost. Thus the traveler is affected by the time and cost of the primary mode and also by the time and cost of any access trips or intermediate steps in the journey, which includes multiple journey links in the primary mode component, that contribute to the door-to-door trip time and cost. Additional service characteristics that will influence the choice of mode include convenience of departure times, reliability of the scheduled travel time, comfort, parking, other amenities and safety (as perceived by the traveler).

Traveler characteristics The two most important traveler characteristics affecting intercity mode choice are income and group size. Income influences the value the travelers place on their time and their willingness to pay for reductions in travel time or better passenger amenities. The size of the traveling group changes the relative cost of traveling by automobile versus by common carrier. Automobile operating costs are insensitive to the number of occupants, whereas common carrier costs increase with group size. Trips long enough to require a stop for meals or overnight accommodations will be substantially affected by party size (7). Table 6 outlines the factors influencing mode choice for each trip purpose. Thus the total demand for mode *k*, for time period *t*, between zones *i* and *j* can be functionally represented as follows:

$X^t_{ijk} = X(E_i, E_j, D_{ij}, M_{ijk})$

where, $M_{ijk} = \lambda(M_{tk}, M_{sk}, M_{trk})$

where M_{tk} = vector of explanatory variables for trip characteristics

M_{sk} = vector of explanatory variables for service characteristics

M_{trk} = vector of explanatory variables for socioeconomic characteristics

TABLE 6 Factors Influencing Trip Generation

Trip Purpose	Trip Characteristics	Service Characteristics	Traveler Characteristics
Work Travel	• Distance between origin and destination	• Cost elastic • Travel elastic • Usually uniform annual pattern	• Income
Business Travel	• Distance between origin and destination • Length of stay • Need for transport at destination	• Cost inelastic • Travel time elastic	• Nature of employment
Recreation travel	• Distance between origin and destination • Length of stay • Need for transport at destination	• High cost elasticity • Low time elasticity • Low convenience elasticity • Strong peaked temporal patterns	• Income • Group size
Personal travel	• Distance between origin and destination • Length of stay • Need for transport at destination	• Less flexibility • Low time elasticity • Low convenience elasticity	• Income • Group size

Bjorkman used a simple formula to forecast intercity traffic. He maintains that the rate of increase in traffic is proportional to the rate of increase in population, the rate of increase in purchasing power, and the rate of improvement of traffic service (5, p. 178). According to Bjorkman, the factors that influence traffic are change in population, change in urban/rural population, change in income, improvement in a particular mode, improvement in other modes, change in fares/cost of a mode and change in fares/cost of other modes. The traffic to and from an area increases in proportion to the product of the said factors and that some of the factors may be given more weight than others by means of power indices. Therefore, the total travel demand, for time period *t*, from origin *i* to destination *j* can be represented as $\Sigma\Sigma\Sigma X_{ijk}$, which is the aggregation of total demand between *i* and *j* by all modes.

Distribution of the Transport Volume for a Mode, between n Routes of that Mode between the Two Regions

The problem of forecasting flow equilibrium in transport networks is solved by supply and demand functions. The supply function for a link indicates cost increases as flow increases up to capacity. The demand function for a pair of regions relates how volume decreases as the cost increases. Furthermore, there exist flow distribution rules: individuals choose minimum cost routes; public services choose routes that maximize their total consumers' surplus (Wardrop's first principle) or minimum journey time (5, pp. 178-179).

Solutions to the problem can be divided into three categories: (a) traffic assignment; (b) mathematical programming; (c) algorithms with fixed and variable demands. Traffic assignment does not prove equilibrium convergence; mathematical programming (linear and dynamic) cannot handle the large-scale problems; algorithms with fixed demand are not realistic- those without fixed demand were worked out by Manheim and by Gilbert in 1968 (the latter proved the equilibrium convergence). The trips between every pair of zones are assigned to the fastest route and traffic is added up on each link. The travel times of the links are adjusted according to the following formula:

$$t_i = e^{[q_i/C - 1]}\, t_0$$

where t_i = travel time after i'th step of iteration

e = 2.718 (basis of Napier's logarithm)

q_i = the flow on the link after the i'th iteration

C= the practical capacity of the link

t_0= initial travel time corresponding to flow equal to C

Using the adjusted travel times a new set of fastest routes between all pairs of zones is found. The process is repeated until the changes in the link flows and in the travel times are sufficiently small from one step of iteration to the next one.

The conceptual model highlights the fact that the demographic and economic characteristics of a place/region are the main factors that explain the generation and attraction of passenger trips. Along with this, the distance decay factor plays an important role. All these together make up the basis for determining the total travel demand in a place/region, disaggregated by trip purpose. Then this total travel demand (disaggregated by trip purpose) is distributed among the modes available to determine the travel demand by mode. The service characteristics, traveler characteristics and trip characteristics influence the mode choice decision. Thus, the final output is the total passenger demand, disaggregated by trip purpose and each of these demands is then disaggregated by the different modes available.

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CHAPTER 6

FREIGHT TRANSPORTATION

CHARACTERISTICS

As explained by Coyle, Bardi and Novack (1), freight transportation demand is derived from demand by customers for the products carried. The cost of transportation then becomes part of the landed cost of the product, affecting both the demand for the product at a specific location as well as demand for the particular transportation service. The characteristics of freight transportation are time, capability, accessibility, reliability, and security.

Transit time is related to the cost of providing the transportation service and also to inventory carrying cost. For example, high-speed, high-cost transportation will permit lower average inventories; the trade-off of the cost increase in transportation must be compared with the potential savings in inventory carrying costs.

The capability of a transportation provider refers to matching the physical characteristics of the freight--size, weight, temperature and handling requirements--and market requirements, such as location monitoring and timely delivery.

Accessibility may be described by the connections between the origin and destination points via a particular mode. For example, most shippers have direct access to motor carriers but not to rail, water or air carriers; these would need intermodal transfers, resulting in added costs and transit time.

Reliability is the consistency of transportation time, or the ability to meet a pickup and delivery schedule. Both modal choice and carrier choice are affected by reliability (1, p. 37). Ballou relates how uncertainty in lead-time results in added safety stocks, thus increasing inventory carrying costs (2).

Security refers to the ability of a carrier to deliver freight in the condition expected. The effects of lost and damaged freight include reduced production and sales by the intended receiver of the freight, increased inventory carrying costs in attempting to avoid these stockout costs, and increased costs of handling loss and damage claims.

Quantitative measures of freight transportation generally are variables that include the value and weight of the freight, distance shipped, and transportation cost and speed. These variables are consistent with those used by Ralston, Tharakan, and Liu (3) in their Bangladesh Transportation Modeling System (BTMS); see Appendix B. The intermodal nature of the BTMS was introduced by Ralston et al. from their experience and observations of transport by ferryboats, and they used cost and time equations to explain the "logical links," which include loading or unloading and intermodal transfers. A generalized model may substitute fixed handling charges and time for the special ferry charges and ferry scheduled times.

The BTMS then computes a utility function, U_{ijkm} (for each shipment of commodity k, between origin and destination i and j, on mode m; see Appendix B.), which becomes the basis for the modal share (probability of using mode m):

$$P(m|ijk) = \exp(U_{ijkm}) / \Sigma \exp(U_{ijkm})$$

Using the Ralston et al. model (Appendix B) as a guide, the required inputs become, for each mode:

VC = variable cost (money per ton-km or ton-mile; money per passenger km)
S = speed (kmph or miles per hr.)
MFC = fixed facilities cost (money per ton or per passenger)
CFC = fixed facilities cost due to commodity characteristics (money per ton or per passenger)
MFT = loading or transfer time
CFT = time due to the commodity characteristics

Typical values for a portion of the required data is readily available and have been tabulated in Table 7. While not industry-specific, these measures provide a starting point and default values that may be used when more detailed data is not collected.

TABLE 7 Published Costs by Mode

Variable	Motor freight	Railroad	Airfreight	Water	Page ref.
Capacity (tons/vehicle)	25	90	100	1,500 & up	143, 170, 226
Revenue ($/ton-mi.)	.2438	.0266	.4634	.0075	226
Speed (m.p.h.)	45	20	453	7	141, 184, 204, 226-27
Loading, transfer time (min./ton)	4	2	4	10	
Modal share, % total ton-mi.	25.7	37.4	.3	16.2	14
Ave. length of haul (miles)	391	650	1,397	441-1,974	201, 225

Source: Coyle, John J.; Edward J. Bardi, and Robert A. Novack, Transportation, 4th ed. (St. Paul: West Publishing Company, 1994).

The modal share variable is one method of handling the multimodal nature of a shipment. For example, if a shipment traveled 50 miles by truck, to a rail transfer facility, and then 1700 miles by rail, finally completing its journey by being drayed 250 miles by truck, the modal share fractions would be .15 (i.e., 300/2000) and .85 (i.e., 1700/2000), respectively, for motor freight and railroad.

The tons and value of freight shipped may be related to the population and employment in the area by:

$$\text{Tons} = a * P^{b} + c * E^{d}$$

$$\text{Value} = e * P^{f} + g * E^{h}$$

Where P and E are population and employment, respectively, and a through h are coefficients to be determined.

IOWA FREIGHT SHIPMENTS

In the 1993 Commodity Flow Survey, Iowa recorded total shipments ("by establishments in mining, manufacturing, wholesale, and selected retail and service industries") (4) of $79.9 billion, weighing 164.5 million tons. These totals represented about 1 percent of the total U.S. value of shipments and 2 percent of the U.S. total weight. In other words, much of Iowa's shipments were high-weight, low-value commodities. The largest category by weight was farm products, which accounted for 33 percent of the volume, but 10 percent of the value. Other high-weight product categories were food or kindred products (24 percent), nonmetallic minerals (15 percent), clay, concrete, glass, or stone products (9 percent), and petroleum or coal products (6 percent). Several manufactured product categories contributed over 5 percent each of total shipment value: food or kindred products; machinery, including computers; chemicals or allied products; electrical machinery, equipment, or supplies. Except for food or kindred products, the weights of each of these categories were less than 5 percent of the total and were grouped in with "other commodities" which shipped approximately 13 percent of the total weight.

By value, 35 percent of Iowa's shipments (60 percent of the weight) stayed in the state, Table 8 shows bordering states received significant shares of the remaining shipments.

TABLE 8 Iowa Shipments to Bordering States

Destination: Iowa border states	Percent of value	Percent of weight
Illinois	10.1	7.1
Minnesota	3.7	3.8
Missouri	3.7	2.7
Nebraska	3.9	3.3
Totals	21.3	16.9

Specific Product Example

An example may clarify the discussion of the conceptual model for manufactured products. One product category produced in Iowa and shipped to destinations both inside and outside the state is Standard Industrial Classification 36, electrical machinery, equipment or supplies. The Commodity Flow Survey (4, p. 19) lists Iowa's shipments of SIC 36 at $4,215,000,000, with a total weight of 568,000 tons. Iowa's SIC 36 shipments are compared with the state's Farm Products and Total shipments in Table 9. While significant in value, at one-half that of farm products, electrical machinery, equipment and supplies shipments were one percent of the weight of farm products and two percent of the ton-miles (because shipments of the former traveled four times the distance of the latter).

Figures V.B.1 and V.B.2 (based on Tables 10 and 11) display the distances shipped for Iowa's total output compared with SIC 36 alone. While over one-half of Iowa's shipment (by value) travel less than 250 miles, the majority of SIC 36 shipments travel over 500 miles. Weight comparisons are similar: Over one-half of Iowa's total shipments stay within a 100 mile distance of their origin, but nearly one-half (48 percent) of SIC 36 products travel over 500 miles. The longer miles per shipment are one factor that would increase the likelihood that electrical machinery shipments would be containerized, requiring intermodal facilities. These differences support the logic of treating specific product categories separately, when data can be attained.

TABLE 9 Iowa Shipments

Category (STCC)	Value ($ million)	%	Tons (1,000)	%	Ton-miles (million)	%	Mi/shipment
36 Elect. Mach.	4,215	5.3	568	.3	380	.8	713
01 Farm Products	8,254	10.3	54,394	33.1	21,632	42.9	141
All commodities	79,900	100	164,544	100	50,478	100	323

Source: Commodity Flow Survey, Table 6, Iowa 11.

TABLE 10 All Iowa Shipments

Distance (mi.)	Median	% value	accum %	% weight	accum%
Under 50	25	22.5	22.5	45.1	45.1
50 - 99	74.5	10	32.5	13.9	59
100 - 249	174.5	22.4	54.9	15.7	74.7
250 - 499	374.5	14.9	69.8	8.3	83
500 - 749	624.5	9.3	79.1	3.5	86.5
750 - 999	874.5	10	89.1	9.2	95.7
1000 - 1499	1249.5	7.3	96.4	3.0	98.7
1500 - 1999	1749.5	3.7	100.1	1.1	99.8
2000 - up	2500	0	100.1	0	99.8

TABLE 11 Iowa SIC 36

Distance (mi.)	Median	% value	accum %	% weight	accum %
Under 50	25	12.8	12.8	11.4	11.4
50 - 99	74.5	4.2	17.1	5.6	17.1
100 - 249	174.5	14.1	31.1	16.7	33.8
250 - 499	374.5	15.1	46.2	18.1	51.9
500 - 749	624.5	17.3	63.5	17.3	69.2
750 - 999	874.5	17.0	80.5	15.1	84.3
1000 - 1499	1249.5	15.4	95.9	13.6	97.9
1500 – 1999	1749.5	4.0	99.9	1.9	99.8
2000 - up	2500	0.1	100.0	0.0	99.8

Mode Choice Matrix

The modes used for Iowa's originating shipments are shown in Table 12 and are predominately truck. These figures differ from the U.S. averages. Iowa's originating shipment values and tons by truck and by rail are higher, largely because Iowa had air, water and pipeline shipments too small to be categorized (some of these are included in "all other"). The comparisons suggest that, in the absence of specific commodity shipment information, Iowa shipments have an 80 percent chance of being shipped by truck vs. a 73 percent chance for overall U.S. shipments. Also, nearly 75 percent of Iowa's originating tonnage will travel by truck, considerably higher than the 53 percent for the entire country. As shipment information for specific product categories becomes available, the modal prediction model will be refined. For example, the following discussion develops modal prediction for one particular product category.

TABLE 12 USA and Iowa Shipments vs Mode

Mode	USA Value (%)	Iowa Value (%)	USA Tons (%)	Iowa Tons (%)	USA Ton-miles (%)
Parcel etc.	8.9	7.1	0.2	0.1	0.3
Truck	72.6	80.3	52.6	74.5	23.7
Air	2.4		0.0		0.1
Rail	4.0	6.5	12.7	15.6	26.0
Water	3.9		17.2		24.0
Pipeline	2.8		10.8		16.1
Truck and rail	1.3	0.4	0.3	0.1	1.2
Other intermodal	0.2		1.2		5.1
All other	3.9	5.7	5.0	9.7	3.6

MODAL SHARES

It is assumed the demand for transportation services for manufactured products is desired in ton-miles (or other weight and distance measurements) by mode. Figure 9 displays a detailed model in diagram form, with the general process of breaking down national economic outputs into regional, and the regional economic model into manufacturing employment and output by industry. Use of input/output tables can further segregate manufactured products requiring transportation into final goods and intermediate goods. Final goods are then transported to a consumer or reseller and intermediate goods are transported to another manufacturer for additional processing or assembly prior to their becoming final goods.

In both cases the volume of manufactured goods, measured by dollar amounts, is allocated to its next destination region, resulting in two origin/destination matrices, which are then aggregated to give overall value flows, from Origin Oij to Destination Dij. A product and weight matrix then allows the value for each product group to be estimated in Tons (or other weight-measure). Thus the transportation demand for product group X, on mode k, between Iowa and region Y, may be approximated.

The intermodal portions present a challenge for analysis. For example, it may be known that 15 percent of final goods in category Z are exported, and 92 percent of these exports are containerized (with the balance being trucked to port), with 40 percent of the exports departing from Seattle and 60 percent from the Port of Miami, Then rail ton-miles to the northwest will increase by .15 * .92 *.40 * tons output * distance (to northwest). Rail ton-miles to the southeast will likewise increase by .15 * .92* .60 *tons output * distance (to southeast). Road tons will be .15 * .08 * tons.

FREIGHT RATES AND CLASSIFICATIONS

Background

Each freight movement described by type and amount of product, between each origin and destination could have a unique price. This situation could result in billions of separate prices, an administrative problem for pricing individual loads of freight. The problem and approaches to solving it predate railroads. Taff reports that overseas operators of riverboats and canal boats classified commodities into a small number of groups, a practice that was later used in the United States and adopted by wagoners and the developing railroads (5). For example, a railroad simplified its freight rate quotations by classifying products as either heavy goods, which were charged on the basis of weight, or light goods, which paid for the space occupied.

Individual railroads refined their classifications by adding new groups, which led to a lack of uniformity and confusion when traffic was interlined. Lieb notes that regional classification systems came before 1900, after the ICC "prodded the railroads to streamline the classification system" (6). Three regional classifications resulted, beginning with the Official Classification of 1887 (east of the Mississippi River and North of the Ohio River), and followed by the Southern Classification (south of the Ohio River) and the Western Classification (Chicago and St. Louis to the West). The consolidated Freight Classification was published in 1919, which made the rules and regulations and the description of products uniform; some ratings differences remained. The Uniform Freight Classification System (for rail freight) replaced the three regional systems for most use in 1952 (5, pp. 354-55).

MANUFACTURED PRODUCTS TRANSPORTATION DEMAND MODEL

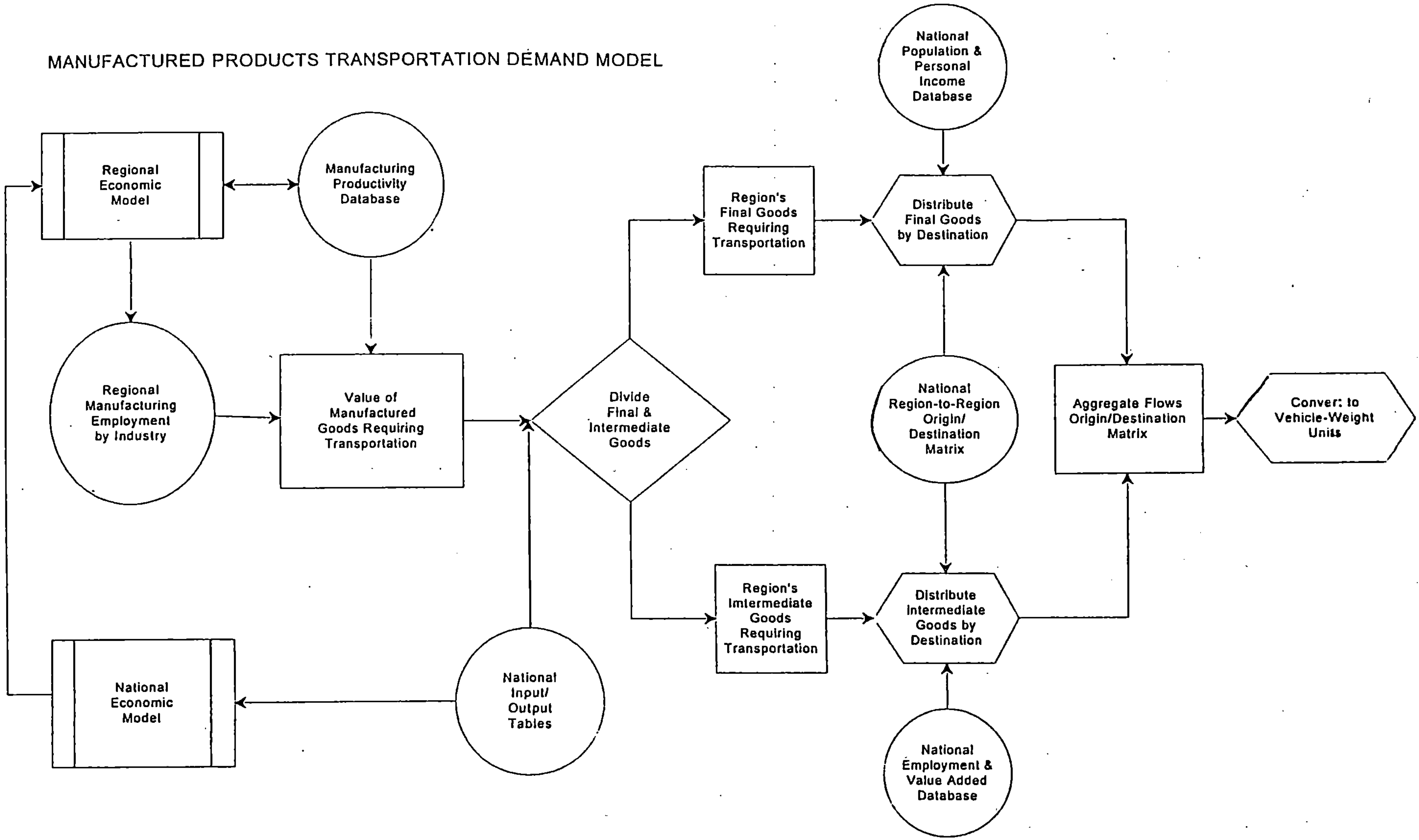

FIGURE 9 Manufactured Products Transportation Demand Model

The National Motor Freight Classification, filed with the Interstate Commerce Commission in 1936, used classification descriptions identical to those used in the rail system because, as explained by Taff, "the task of formulating completely new classifications was so formidable" (5, p. 407).

Ratings

The class rating system was developed to simplify the process of determining freight charges into a basic formula (7):

Freight charge = Weight X Rate

The weight is expressed in hundred-pound units (CWT) and the freight rate is quoted as a cost per hundredweight. The rate is, in turn, based on the distance and the product being shipped. Distance has been simplified into a rate basis number, which is based on the distance between map segments, rather than the point-to-point distance for each particular shipment (7, p. 273).

Reference to product attributes is simplified by giving each product a rating number, which is a percent of the first-class or standard product rating. Thus, a product with a rating of 100 would be charged the standard rate and a product with a rating of 50 would be charged one-half that rate. In the first Uniform Freight Classification, over 23,000 product descriptions were grouped into 31 classes, from 13 to 400. The classes are: 400, 300, 250, 200, 175, 150, 125, 110, 100, 92.5, 85, 77.5, 70, 65, 60, 55, 50, 45, 40, 37.5, 35, 32.5, 30, 27.5, 25, 22.5, 20, 17.5, 16, 14.5, and 13 (5, p. 359).

The National Motor Freight Classification follows the pattern of the rail classification but uses 23 groups, which ranged between 35 and 500. The NMFC classes are: 500, 400, 350, 300, 250, 200, 175, 150, 125, 110, 100, 92.5, 85, 77.5, 70, 65, 60, 55, 50, 45, 40, 37.5, and 35. The lowest four classes were assigned to truckload (TL) freight only. The Coordinated Motor Freight Classification, in place by 1948 for shipments in New England, reduced the number of classes to five. Classes were determined by density, with no differentiation between less-than-truckload (LTL) and high volume shipments (5, pp. 362, 365).

Products are rated by factors including (6, pp. 217-218):

- Shipping weight per cubic foot
- Liability for damage
- Liability for damage to other commodities with which it is transported
- Perishability
- Liability for spontaneous combustion or explosion
- Susceptibility to theft
- Value per pound in comparison with other articles
- Ease or difficulty in loading or unloading
- Stowability
- Excessive weight
- Excessive length
- Care or attention necessary in loading and transporting
- Trade conditions
- Value of service
- Competition with other commodities transported
- Quantity offered as a single consignment.

The National Classification Committee composed of up to 100 motor common carrier employees and owners, rates new commodities and acts on applications to reclassify existing commodities. Pugh emphasizes the revenue neutrality of the NCC; the transportation characteristics determine the rating; economic considerations "are reflected in the rate tariffs" of the carriers (9). While each of the factors listed above may influence how a product is rated, the ICC has ruled that product density, stowability, handling, and liability are the four determining factors (1, p. 362). Bohman explains that the National Classification Committee relies strongly on its "Density Guidelines" (see Table 13): "Now there may be circumstances in which other transportation characteristics might prompt the NCC to assign ratings higher or lower than called for in its density guidelines. . . don't underestimate the weight accorded to density in the rating determination" (10).

Although no specific formulae are used to assign a commodity to a particular class, the four factors are considered in conjunction by a carrier classification committee. An individual carrier may establish a commodity classification that differs from the national classification; this individual carrier classification is termed an exception and takes precedence over the national classification.

TABLE 13 National Classification Committee's "Density Guidelines"

Class	Min. Ave. Density (Pounds Per Cubic Ft)
500	less than 1
400	1
300	2
250	3
200	4
175	5
150	6
125	7
110	8
100	9
92.5	10.5
85	12
77.5	13.5
70	15
65	30
60	30
55	35
50	50

Source: Ray Bohman, "Bohman on Pricing: Get to know the NCC guidelines," *Traffic Management*, Vol. 29 (January 1990), p. 25.

Exception Ratings and Commodity Rates

The desire for freight charges different (lower, usually) from those calculated according to the class rate system may come from several fronts, such as shippers or potential shippers trying to match a competitor's costs, or a carrier competing for freight. In addition to the exception ratings, shippers may protest to the classification committee that a product is rated too high, citing lower ratings for analagous products. Carriers may use the same strategy in protesting that a rating is too low (6, p. 218). Changed ratings resulting from protests apply to all shippers. Requests for exception ratings arise from specific competitive situations and tend to apply to a limited number of shippers (because of product or packaging description, shipment sizes, or area served), even though the exceptions are published in the class rate tariffs.

Commodity rates (dollar amounts, not ratings, as above) are usually lower than the class rates and are for movements of a specific commodity from one stated point to another. One estimate is that commodity rates account for a majority of rail, truck and water tonnage (but not the number of shipments) (6, p. 225). To the extent that more shipments would be made under commodity rates, the rate simplification objective of the class rate system has been defeated. This same comment would apply to contract pricing of transportation, further amplifying the complexity of transportation rates. As Lieb points out, "The shipper is legally entitled to the lowest published rate that might be applied to his traffic. That is, at any given time, only one legal rate applies to a specific shipment handled by a specific carrier" (6, p. 223).

TABLE 14 National Classification Committee's Value Guidelines

Class	Max. Ave. Value (Per Pound)
500	$89.12
400	71.29
300	53.47
250	44.56
200	35.65
175	31.20
150	26.74
125	22.27
110	19.60
100	17.82
92.5	14.25
85	10.70
77.5	7.12
70	5.34
65	3.53
60	2.12
55	1.42
50	.71

Source: Ray Bohman, "Bohman on Pricing: How 'value' fits into the rating equation," Traffic Management, Vol. 30 (April 1991), p. 25.

Simplification Attempts

With railroads moving away from less-than-carload shipments and toward contract rates, the NMFC became the dominant classification system. In 1977 (before the Motor Carrier Act of 1980), Snow criticized the rate structure for LTL freight as being "cumbersome and needlessly complex" and not based "on genuine cost differences" (13). Davis, also, had supported the use of more precise cost data in constructing rates. He noted that pricing for transporting containers was based on "the size of container or weight loaded rather than the standard classification of the product" (14).

Nearly two decades after deregulation of trucking, Foster called for "junking the old pricing system based on the NMFC, which no longer has any relevance to how LTL services are bought and sold." He proposed that rates be based "on simple variables such as cents per pound, density and distance moved," with a simple factor for liability. Both shippers and carriers would avoid existing costs of rating, and of payment and auditing services (15). Some carriers have begun testing a one-page, net rate pricing scheme, which has discounts and accessorial charges built-in and customized for the individual shipper. Cassidy reports that shippers have welcomed pricing simplification "when it promotes billing accuracy and provides savings" (16). Such simplification has been introduced in several ways for multimodal freight movements. For example, the "any commodity rate" and "freight-all-kinds" rate de-emphasize the shipment value and have been used for several piggybacking plans and for containerized imports (6, p. 226; p. 425).

CONCLUSIONS FOR THE PROJECT

Freight charges are typically calculated by multiplying a rate times the weight, with the rates varying by product or product classification. Even with the faults some writers attribute it, the NMFC provides a reasonable starting point for describing freight. For the proposed model, a "typical" freight product would be a class 100 shipment, in terms of density and value. A simple multiplier may then adjust freight costs for shipments clearly unlike class 100 commodities. For example, a high-valued product, with a 400 rating, would have a multiplier of 4.

Multiple modes do not necessarily mean more complex freight charge calculations. There already exist freight rate schemes based on a container or weight unit and not on value of products carried. A recommended future modification may be to specify containerized shipments (expressed twenty-foot equivalent units, or TEUs). For example, one state transportation plan includes Containerized Cargo as one of eleven separate product categories (17).

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APPENDIX A: SURVEY

SURVEY: QUESTIONS, SAMPLE

A survey was sent to each state transportation department to assess how their planning programs have been adjusted to reflect the new direction set by ISTEA. A four-page questionnaire was sent to the planning director in each of the 50 states. The objectives of the questionnaire were to:

1. Identify states' multimodal perspectives and barriers encountered in developing multimodal plans
2. Determine resources and skills needed for multimodal planning
3. Identify preferences for future ISTEA-type legislation

Forty-six states returned the surveys in complete or partially usable form.

RESULTS

States' Responses

Following passage of ISTEA, 96 percent of the states responding had produced new or updated transportation plans by the end of 1996. When asked about their progress in developing the transportation management and monitoring systems, the state planners indicated that the intermodal transportation management system was tied with public transportation for last place; 52 percent of the states reported that system as complete or in-process. Seventeen states (37 percent) indicated no plans to complete this management system. ISTEA may have increased the attention given to transportation involving more than one mode but, as Table 15 shows, systems for the more traditional topics like managing pavement and monitoring highway traffic drew more than twice the attention of intermodal transportation. (Graphs corresponding to the tabulated data appear at the end of this Appendix.)

The states were next divided into two groups by geographic area (e.g., largest 25 states in square miles vs. smallest 25), by population, by population density (people per square mile), and by percent urban population. For each grouped comparison, the number of positive responses in the first group were compared with the number of positive responses in the second, and chi-square values calculated to test the null hypothesis: "The progress toward completing a particular Transportation Management System does not vary by group (when states are grouped by area, population, density or urban concentration)." Table 15 lists the chi-square values and critical values of chi-square for differences significant at the .05 and .10 levels. There was no indication that states' efforts for their Transportation Management Systems varied by size of state, population, density or urban portion.

Specific modes or transportation system combinations

Another indication of the attention given to intermodal transportation was furnished by responses to a question of which modes or systems were addressed by the states' new or updated plans. Responses for passenger and freight transportation were separately accumulated and ranked in Tables 16 and 17. As might be expected, passenger travel by automobile received specific mention by nearly all states, but bicycle and pedestrian travel were a close second. The attention given the bicycle and pedestrian modes may reflect interest in an inexpensive way for states to not let others outrank them in environmental conscientiousness. The three intermodal combinations--bus-rail, bus-air, and air-rail--were included in 59 percent, 52 percent and 45 percent, respectively, of state plans. Passenger transportation by water was included by 16 states (36 percent) in their transportation plans.

TABLE 15 Transportation Management Systems

Transportation Management Systems, Completed or In-process	Percent of states (n = 46)	Chi-square (df = 3)
Pavement of Federal aid highways	100	.52
Bridges	98	.45
Highway safety	85	.49
Traffic congestion	83	.71
Public transportation	64	2.34
Intermodal transportation	63	1.48
Traffic monitoring for highways	91	.19

Chi-square critical values: .05 = 7.815; .10 = 6.251.

The chi-square test of the null hypothesis, "Passenger modes and combinations included in state transportation plans do not vary by area, population, density or urban concentration," produced no values exceeding the critical levels.

The freight combination of truck-rail was included in 82 percent of the state plans, just behind the individual modes of rail and truck. The other intermodal freight combinations of truck-air, rail-water, and truck-water were included in over one-half (59 to 61 percent) of the states' plans; see Table 17. The truck-rail combination received the most emphasis of any passenger or freight intermodal combination, on par with the dominant single modes. The remaining combinations were of lessor importance in the states' plans.

The null hypothesis, "Freight related modes and combinations included in state transportation plans do not vary by area, population, density or urban concentration," was rejected for pipelines (at the .10 level). The transportation plans of larger states (12/44 vs. 4/44), less dense states (11/44 vs. 5/44), and more urbanized states (10/44 vs. 6/44) were more likely to include pipelines. This result is consistent with the observation that the oil-producing states tend to be large, with dispersed populations, and the oil-refining states tend to be industrialized with major population centers.

Infrastructure Needs Addressed by Traffic Network Models

Intermodal freight facilities and intermodal passenger facilities were included in 11 and 9 percent, respectively, of the states' traffic network models. The infrastructure needs addressed by these models were dominated by state highways (39 percent) and county and city streets and roads (18 percent). As displayed in Table 18, terminals and facilities for other individual modes received scattered mention. If the "intermodal" objective of ISTEA is to be achieved, the traffic network models used by state planners will need to be updated to include trips or hauls involving more than one mode and the infrastructure required to allow the intermodal transfers of freight and passengers. The null hypothesis, "Infrastructure needs in traffic network models do not vary by area, population, density or urban concentration," was not rejected for any of the categories listed in Table 18.

TABLE 16 Passenger-related Modes and Combinations

Passenger-related modes and combinations	Percent of states (n = 44)	Chi-square (df = 3)
Private passenger vehicles	98	.93
Bicycle/pedestrian	98	1.96
Urban transit (all modes)	91	.68
Intercity bus	89	1.85
Air passenger	84	1.38
Intercity railroad passenger	84	1.19
Light trucks and vans	80	2.06
Bus-rail	59	1.66
Bus-air	52	2.58
Air-rail	45	.97
Water passenger	36	1.02

TABLE 17 Freight-Related Modes and Combinations

Freight-related modes and combinations	Percent of states (n = 44)	Chi-square (df = 3)
Freight railroads	89	3.28
Freight motor carriers	84	2.03
Truck-rail	82	4.53
Air freight carriers	73	.34
Truck-air	61	1.30
Rail-water	59	2.27
Truck-water	59	2.27
Water freight carriers	59	.46
Pipeline	36	7.28*
Other	14	1.96

* Differences significant at the .10 level.

TABLE 18 **Infrastructure Needs in Traffic Network Models**

Infrastructure needs in traffic network models	Percent of states (n = 44)	Chi-square (df = 3)
State highways	39	.71
County & city roads & streets	18	.38
Intercity rail passenger facilities	14	.69
Urban transit facilities	14	1.85
Intercity bus terminals	11	1.67
Intermodal freight facilities	11	3.33
Commercial airports	9	3.20
Intermodal passenger facilities	9	2.79
Rail freight track & yard facilities	9	2.79
Air freight facilities	7	4.89
General aviation airports	7	4.89
Pipeline terminal facilities	5	5.87
Water freight port facilities	5	2.67
Water passenger terminals	2	4.00
Other	2	4.00

Multimodal Issues in New or Updated Plans

When presented with a list of eleven specific multimodal issues, the top three identified by state planners were urban rail-highway conflicts (57 percent), rural rail-highway conflicts (55 percent), and intercity bus and rail terminal joint location (48 percent). As Table 19 indicates, highway-related issues appeared frequently--such as freight and passenger terminals' impacts on roads--and were included in comments in the "other" category.

Null hypotheses testing suggested two issues for further inquiry. First, rejecting (at the .10 level) the statement, "The inclusion of intercity bus and air terminal joint locations in new or updated statewide plans does not vary by area, population, density or percent urban population," lends support to interpreting the data as showing that states with larger areas and lower densities were more likely to include this issue. Smaller states were less likely to have airports and lower density states may be more likely to employ intercity bus transportation rather than light rail.

The second null hypothesis to be rejected (also at the .10 level) concerned "other" multimodal issues: "The inclusion of other multimodal issues (see Table 19) does not vary by area, population, density or urban concentration." Geographically smaller states were more likely to list "other" multimodal issues in response to this question.

TABLE 19 Multimodal Issues in New or Updated Statewide Plans

Multimodal issues in new or updated statewide plans	Percent of states (n = 44)	Chi-square (df = 3)
Urban rail-highway conflicts	57	.77
Rural rail-highway conflicts	55	1.52
Intercity bus & rail terminal joint location	48	1.67
Freight terminal impact on roads	36	3.19
Rail & water freight terminal joint location	36	2.26
Passenger terminal impact on roads	30	3.31
Reduces highway use due to rail freight	30	2.80
Intercity bus & air terminal joint location	27	6.26*
Highway investment on motor carrier terminal location	23	2.40
Passenger terminal impact on parking	20	.44
Highway investment on warehouse & DC location	20	2.22
Other multimodal issues: Access (friendly design, landside, intermodal) Diversion from highway Focus on truck-rail transfer Integrating bicycle/pedestrian with roads & bridges Interconnected rail-freight-air-water service on highway operations Light rail-airport, commuter heavy rail Truck-rail movement of agricultural products	20	6.74*
* Differences significant at the .10 level.		

Methods Used for Identifying Future Needs for Transportation Infrastructure Investment

Explanations of the lack of integrated planning may be indicated by the methods which states use to identify future needs for transportation infrastructure investment. The rankings of Table 20 show that more than twice as many responding states (67 percent) employ non-network models than network models. In other words, individual projects were analyzed without full consideration of their effects upon the transportation network. Twenty-four percent had a passenger network model, but no freight model, while 9 percent had separate network models for passenger and freight transportation. Fifteen percent claimed single integrated network models. Given the complexity of a state's transportation system, resorting to less-than-complete analyses is not surprising. Forty-eight percent of the states employed benefit-cost analysis, a structured model that attempts to compare total societal benefits to total societal costs, "whether they be monetary or nonmonetary in nature" (1). Twenty-four percent also used regional economic impact models, a sign that wider analysis is taking place. Six individual states (13 percent) mentioned use or development of other network or regional models.

The chi-square test of the null hypotheses, "The use of mode specific network models for identifying future needs for transportation infrastructure investment does not vary by area, population, density or urban concentration," produced one value exceeding the critical value (at the .10 level). States with more urbanized population and with larger land areas were more mode-specific. Conversely, states with more dispersed population may have broader infrastructure needs.

Training Needs Identified Due to Multimodal Emphasis of ISTEA

Even if more states had integrated models available, the skills necessary for applying them may need upgrading. As Table 21 shows, a majority (67 percent) require backgrounds in Geographic Information Systems. Over 40 percent of the states required training in five additional categories: transport economics, benefit-cost analysis, financial analysis, transport network development and modeling, and inter-city freight demand forecasting. One-fifth to one-third of the respondents identified seven more training needs, further evidence of the education support that will enable implementation of multimodal transportation planning. Chi-square tests identified no null hypotheses of the form, "(Specific) training needs due to the multimodal emphasis of ISTEA do not vary by area, population, density or urban concentration," that were rejected.

TABLE 20 Methods for Identifying Future Needs for Transportation Infrastructure Investment

Methods for identifying future needs for transportation infrastructure investment	**Percent of states (n = 46)**	**Chi-square (df = 3)**
Mode & system non-network models	67	.87
Benefit-cost analysis	48	1.09
Mode specific network models	26	7.27*
Passenger network model, but no freight model	24	1.76
Regional economic impact models	24	2.46
Single integrated network model	15	3.88
Separate passenger & freight network models	9	1.07
Other: HPMS package, system-wide model is under development Person trip model, separate transit model Policies Public involvement Regional prioritized needs REMI for economic impact analysis	13	.00

*Differences significant at the .10 level.

TABLE 21 Training Needs Identified Due to Multimodal Emphasis of ISTEA

Training needs identified due to multimodal emphasis of ISTEA	Percent of states (n = 46)	Chi-square (df = 3)
Geographic Information Systems	72	4.13
Transport economics	54	.64
Benefit-cost analysis	50	.83
Financial analysis	50	.83
Transport network development & modeling	50	1.05
Inter-city freight demand forecasting	48	.87
Railroad system planning	37	.94
Public finance	33	1.07
Public transit system planning	33	2.90
Inter-city passenger demand forecasting	30	5.69
Business logistics	26	.93
Air transport system planning	24	3.54
Water transport system planning	24	3.38
Intra-city passenger demand forecasting	13	2.22
Other: Application of business planning practices to non-govt transportation Bicycle/pedestrian planning Dept. has extensive on-going training program Future planning skills and needs study Information systems in general, e.g., data warehousing, Oracle Not at this time, but see a need for GIS databases	15	1.58

Funding Flexibility

Consistent with the shifting emphasis to multimodal transportation was increased flexibility in spending federal funds. Where most prior allocations were restricted to one mode, such as a highway project or Amtrak, the objective of ISTEA was to encourage projects involving more than one mode by reducing the restrictions on spending. When respondents were asked if they felt that ISTEA had accomplished the objective of making federal funding programs more flexible, 57 percent said yes and 43 percent said no.

While a clear majority agreed that the federal funding programs were more flexible under ISTEA, it is notable there were 19 states responding "no." Accompanying the negative responses were the following comments:

- In general, funding is less flexible under ISTEA than under previous acts.
- Flexibility between transit and highways, but between them and other modes has not occurred. Intent was good, but too many limitations.
- Cannot easily use funds on intercity passenger and freight (rail, ports).
- Important progress has been made but the problem of less than full funding continues to hinder flexibility.
- ISTEA changed very little unless states endorsed the change themselves.

Funding flexibility to allow, even promote, multimodal programs appears to be one step in the right direction. New legislation may build upon the partial success of the ISTEA in reducing funding restrictions.

Future Legislation

The survey asked what features state transportation planners considered desirable for inclusion in a reauthorization bill. (The original provisions of ISTEA expired on September 30, 1997. Congress was debating nine bills for reauthorization during June 1997 (2).) Responses are ranked in Table 22. The leading requests were to expand the State Infrastructure Bank program, from the initial 10 states (3) to all states (41 percent), retain the current apportionment formula (35 percent), and a separate program for bridge replacement (also 35 percent). The least support was expressed for the ethanol tax exemption (2 percent) and appropriations for demonstration projects (2 percent); the use of federal taxes for deficit reduction received no support.

One null hypothesis was rejected: "The desirability of a set aside for rural areas in the reauthorization of ISTEA does not vary by area, population, density or urban concentration." States in the top 25 by land area but the lower half in terms of population and density included this feature more often than did less rural states.

TABLE 22 What Features are Desired in the Reauthorization of ISTEA?

What features are desired in the reauthorization of ISTEA?	Percent of states (n = 44)	Chi-square (df = 3)
State infrastructure bank funding for all states	42	4.09
Current state apportionment formula	36	1.30
Separate program for bridge replacement	36	.25
Set aside for large urban areas	29	3.47
Set aside for enhancements	24	2.46
Separate program for congestion & air quality management	22	1.90
Separate program for safety improvements	22	.30
Special trade corridor funding	22	4.44
Amtrak eligibility for STP or FTA funds	20	.33
Set aside for rural areas	22	6.87*
Turn back federal taxes to the states	18	.42
Keep fuel tax exemption for ethanol	2	--
Special appropriations for demonstration projects	2	4.00
Use of federal tax for deficit reduction	0	--
Other: Dedicated funding to solve rail/highway conflicts. More flexibility (2 states) NHS (2 states) Support Step 21 initiative (4 states)	33	1.61

* Differences significant at the .10 level

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2. David Barnes, "Washington Report: House Gridlock?" Traffic World, June 16, 1997, pp. 13-14.
3. U.S. Department of Transportation, "29 Additional State Are Approved to Participate In State Infrastructure Bank (SIB) Pilot Program," June 19, 1997.

APPENDIX B: EXPLANATION OF RALSTON ET AL. VARIABLES

Cost and time are related to distance and speed by the following:

Cost = L * VC * LCM * SCM

where:

L = length of link

VC = variable cost (money per ton-km or money per passenger km)

LCM = link's unique cost (multiplier nominally 1), reflecting link's state of repair

SCM = mode's seasonality cost (multiplier nominally 1)

Time = (L / S) * LTM * STM

where:

S = speed (kmph)

LTM = link's unique time (multiplier nominally 1), reflecting link's state of repair

STM = mode's seasonality time (multiplier nominally 1)

The following cost and time equations explain the "logical links," which include loading or unloading and intermodal transfers:

Cost = FFC * LCM * SCM

where:

FFC = fixed ferry charge (money per ton or per passenger)

and:

Time = FFT * LTM * STM

where:

FFT = known delays (i.e., fixed ferry time in hours)

Cost = (MFC + CFC) * NCM

where:

MFC = fixed cost (money per ton or per passenger)

CFC = fixed cost due to commodity characteristics (money per ton or per passenger)

NCM = node cost multiplier (nominally 1)

Time = (MFT + CFT) * NTM

where:

MFT = loading or transfer time

CFT = time due to the commodity characteristics

NTM = node time multiplier (nominally 1)

The utility function (for each shipment of commodity k, between origin and destination i and j, on mode m) is:

$$U_{ijkm} = B_{1k} C_{ijkm} + B_{2k} T_{ijkm} V_k + B_{3k} d_1 + B_{4k} d_2$$

where:

V = value of commodity k (for passengers, V = 1)

d_1 = toggle (1 if rail, 0 for other modes)

d_2 = toggle (1 if water)

B_{1k} = weight (to be determined, expected negative)

B_{2k} = weight (to be determined, expected negative)

B_{3k} = weight (to be determined, either sign)

B_{4k} = weight (to be determined, either sign)

The modal share (probability of using mode m) is then:

$$P(m|ijk) = \exp(U_{ijkm}) / \Sigma \exp(U_{ijkm})$$

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