Pre-Meeting Proceedings*

Transportation Research Forum

34th Annual Meeting

Editor:
Russell B. Capelle, Jr.

October 21-23, 1992
St. Louis, Missouri

*"The St. Louie Book"

INTERCITY FREIGHT TRANSPORTATION DEMAND THEORIES AND MODEL SYSTEMS

Paper prepared for 34th Transportation
Research Forum (TRF) Annual Conference
St. Louis, Missouri, USA October, 1992

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April, 1992

Abstract

Forecasting the demand for intercity freight transportation deals with the behavioral analysis of agents in freight transportation system, the theories and approaches for demand forecasts, and the model formulations for specific applications. This paper focuses on the discussion of the theories and models for intercity freight transportation demand study. Instead of analyzing the structures of various models, the major families of demand models in freight transportation system are examined systematically. Based on in-depth analysis of the research orientations of models and the theories for model formulation, a systematical classification of various freight transportation demand models is provided for comprehensively presenting the complex demand model families, the existing approaches, and the interrelationships among model families.

INTERCITY FREIGHT TRANSPORTATION DEMAND THEORIES AND MODEL SYSTEMS

by Pingning Shen

1 Introduction

The development of intercity freight transportation demand models is very helpful for quantitatively evaluating and forecasting the impacts of various policies and regulations involving in investment, maintenance, and operation of transportation facilities. In addition, the development of the great variety of demand models is essential to the analysis of the diversity of decisions or problems faced by planners, such as the studying optimum distribution of commodity, the optimizing the choice of vehicle fleet and route, and the analyzing multiple behaviors on complicated and competitive transportation market. Based on the various demand models, transportation planners now have alternative tools for better assessing freight transport demand. However, since the analysis of freight transportation demand deals with many fields, the demand forecasting models vary according to the various objectives of the research, the theories for the development of models, and the modeling approaches and techniques. In order to choose or develop a model to fit the requirements for solving practical problems, a comprehensively understanding of the framework of freight demand theories, model systems, and the primary background for designing models is essential. For this purpose, this paper, instead of discussing the various demand models individually, systematically presents the freight transportation demand theories and the model families, and explores the classification of various freight demand models in context of the theories of model formulation and the modelling approaches. The classification of demand model families gives new insights about intercity freight demand model systems.

2 Analysis of Freight Transportation Demand

Freight transportation is recognized as an economic activity since the movement of commodity is a part of economic process of production and consumption. Although in some aspects the freight movement has some similar characteristics as the movement of passengers, the movement of commodity has its special features. In comparison, both the movements of passengers and commodities are dependent on the vehicles, have peaks and troughs of activity during weekdays or seasons, and are sensitive to the level of economic activity and transportation service. However, the obvious dissimilarities, which influence the selection of theories and the formulation of models for predicating the demand for freight transportation, are recognized as some aspects. Firstly, the movement of commodity involves in much wider variety of vehicles and more specialized services and equipments. Secondly, the derived demand for the movement of commodity arises from the needs at the locations of consumption that are spatially separated from the locations of production, and from the demand for particular commodities or services at particular places. Thirdly, the movement of commodity involves more economic agents including various private and public firms of industry, agriculture, commerce, transport, and technology. Fourthly, the movement commodity is more sensitive to exogenous economic force and related policy or decision from government or firm. Therefore, the development of a highly abstract and sophisticated model for analyzing demand for freight transportation, to some extend, is of difficulty.

The difficulty of modeling the movement of commodity is also due to the complexity of the demand analysis itself. It is recognized that freight transportation demand arises through a combination of spatial, physical, economic and social factors leading the non-homogeneity in the distribution of resources, specialization of production, or any combination. To be more concrete, the demand for freight transportation results from the special economic activities. These activities are 1) the structural changes or growth in various sectors of the regional economy, such as building new industrial or manufacturing plants, and developing natural resources; 2) the changes in economic regulation or government policy or consumption of goods, such as adjusting policy of import or export, changes in prices of raw materials, and technological innovation in industry; 3) the changes in distribution of population and goods in different geographic regions, such as developing new areas, and constructing new towns. All these activities represent that the analysis of demand for freight transportation involves in the study of many economic attributes. As such the modeling freight transportation demand is associated with the analysis of the economic accepts, such as the theory of consumer or the theory of a firm.

Furthermore, according to the economic demand theory, freight transportation is a factor of production. Consequently, the demand forecasts should consider the production, the distribution, and the location problems faced by a firm. The firm makes decisions on selecting a location for the plant or on purchasing its transportation services for the purpose of maximizing profits or minimizing total costs. However, to make such decisions is of difficulty since the firm confronts with complex choices. According to Chiang et al.'s (1981) points of view, decisions made by a firm in freight transportation can be represented as a complex hierarchy of choices which include 1) long-run location choice: the choice relating to location of the firm; 2) intermediate-run production choice:

the choice relating to the technology of production and level of output; and 3) short-run logistic choice: the choices relating to the transport of commodities. Most models for freight demand forecasts concern with the short-run logistic choice, such as the origins of input, the destinations of output, the modes of transport, the size of shipment, the optimum paths of freight flows. Therefore, developing a model for decision making purpose should consider the complex choices faced by a firm and the various specific problems.

In addition, it is noted that the study of freight transportation demand involves in analyzing the multiple behaviors of the economic agents, which obviously influence the formulation of demand models. In freight transportation system, the shippers, the carries, and the government could be viewed as three major agents who have an interest in freight demand models. However, since they view the problems from different domains, the requirements for constructing models for demand forecasts are different. The government oriented models are designed as planning tools to evaluate the alternative macro-scale choices, such as the choice of infrastructure investment planning or the choice of regulatory policy. Therefore, the demand models derived for this purpose are typically large-scale and comprehensive and they are usually utilized to analyze long-run location or intermediate-run production choices. Unlike the government oriented models, the carrier oriented models concern about marketing or pricing analysis. The models are developed to analyze the level of transport service to be offered and the resulting profits which can be achieved in the competitive market. Thus, the models could be used to analyze the short-run logistic choice. The producers or the shipper oriented models normally concern about the selection of locations of supply for their input materials or places to send their products, and the selection of logistics and transport strategies for these inputs and outputs. Thus the models developed for fitting shipper's requirements are usually sophisticated and specific disaggregate modal choice models and they are very useful for the study of short-run choice. All these indicate that an abstract and sophistic model should have capability to predict demand associated with the behavior analysis.

In summary, one of the major objectives of intercity freight transportation demand analysis is to study the relationship between temporal and spatial distribution of economic actives and their demand for transportation. The output of the analysis generally describes relationship between commodity flows and the characteristics of freight transportation system. When expressing such relationship in a mathematical form a demand model results. Based on the various demand models designed for solving specific problems, the transportation planners can clearly explain the behaviors of agents and predict the commodity flows utilizing proposed transportation services and facilities, so that alternative transportation plans and policies can be more objectively evaluated.

3 Theories for Intercity Freight Transportation Demand Analysis

The models designed for analyzing the demand for intercity freight transportation, in general, are based on the economic theory, the classic Newton's law of gravity, and the optimization theory. The models constructed from these theories usually deal with different research realms and different modeling techniques. Based on the economic theories, the models are derived to forecast the demand for freight transportation by considering transportation as one of the inputs into the production or the marketing process of the firm. Since the econometric approaches are usually used to formulate this relation, the models could be defined as econometric models. To formulate the econometric models, the firm's demand for the commodity itself is first analyzed and then the transportation demand function from that is derived. The econometric models (except input-output model) focus on the study of relationship among freight shippers, carriers, and government policy makers. Thus, the models are very useful for analyzing the impacts of various polices on firm, investment, implementation, and the demand for transportation. Most of econometric models are employed to study either freight demand side or supply side or both.

Based on the Newton's Law of Gravity, the spatial interaction demand models are developed. The basic assumptions for formulating a gravity type of freight demand model are that commodity flows between origins of production and destinations of consumption are proportional to the excess supply in origins and excess demand in destinations and are inversely proportional to some measure of the distance between origins and destinations. The gravity models are derived to simulate the shippers' decision on the distribution of freight flows for the purpose of allocating a certain amount of commodities to the locations of demand. The gravity models concern about the mutual relations of the freight shippers, carriers, and the consumers. The models are aggregate in nature and commonly used for analyzing intercity commodity distribution problems.

According to the optimization theory, the distribution and assignment of commodity flows, the demand for transportation facilities, and the multiple behaviors of agents can be precisely predicated using network models. The models formulated according to optimization theory can be viewed as two common types: the special price equilibrium models and the network equilibrium models. The spatial price equilibrium model is designed to analyze the interactions of the producers, the consumers, and the shippers using network optimization approach. The basic assumption of formulating spatial price equilibrium models is that if the surpluses and deficits of commodities are at different locations, the commodities will flow from the locations of excess supply to the locations of excess demand. The spatial price equilibrium models postulate that the demand for freight transportation is derived from the market price across regions, and if the fixed demand is satisfied the equilibrium process of transport is achieved. Thus, the models are developed to forecast the demand for commodities at markets and the equilibrium between spatially separated markets. While the network equilibrium model is formulated to analyze the equilibrium process of transport and the behaviors of carriers who make decision on the choice of network path to carry products. The model deals mainly with the realm of interactions of the shippers, the carriers, and the consumers. The model has capability to analyze the multiple behaviors on the freight transport network and predict the distribution and assignment of the demand of commodities at all locations of consumption. Thus, the network equilibrium models could be applied to analyzing either small firm's choice of minimum paths for minimizing its transport costs or the large firm's choice for minimizing total costs on transport network.

The above analyses indicate that each family of the models is developed according to different theories for specific problem domains. The relations of theories, demand models, and the research domains can be depicted by Figure 1.

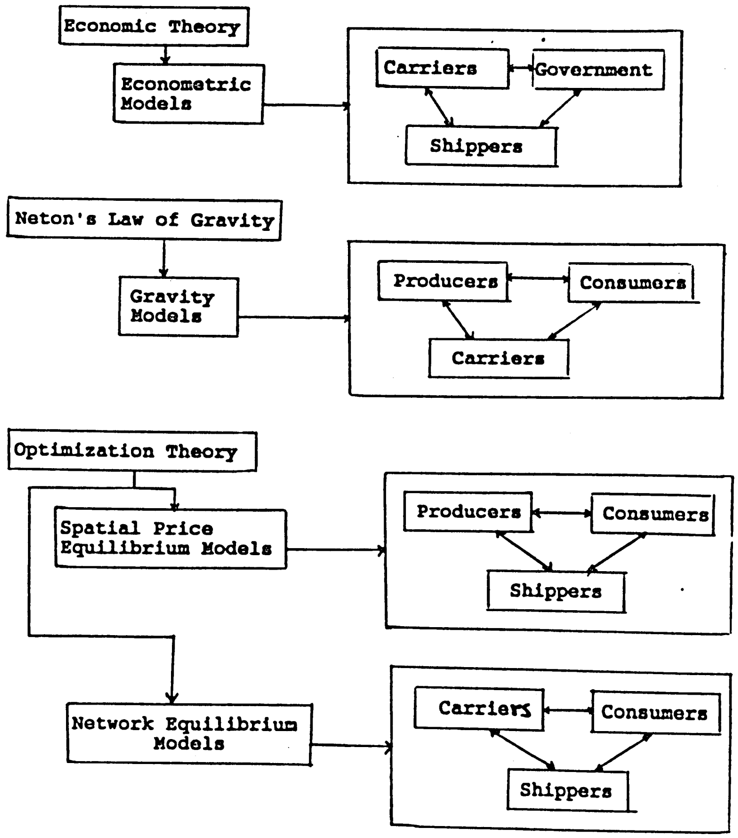

Figure 1 The Theories and Model Research Orientations

4 The Classification of Various Demand Models

The classification of intercity freight transportation models is very helpful for transportation planners to know the families of demand models, the modeling theories, the existing methods and techniques, the relationships among various types of models, the difference of model structures, the selection of models for practical applications, and the further development of models. The classification of various models described in this section is according to modeling theories and research approaches.

The great variety of demand models based on the different criteria, in general, can be classified into several families. Firstly, according to the difference of the data source or the behavior characteristics analyzed by model, the aggregate and disaggregate models can be easily identified. The aggregate modeling process usually starts with the data collection at the zonal level and the demand model is then estimated using these aggregate or averaged data. The aggregate models are commonly used to predicate market demand of all consumers directly. While the disaggregate models utilize economic theories to capture the choice behaviors either the shippers or the carriers or both. The model calibration relies on the observations at the individual level. Secondly, the families of demand models can also be distinguished as simultaneous (direct) and sequential (indirect) models according to difference of prediction process. A simultaneous model implies that the decision maker is presumed to choose all choices (e.g., destination, mode, and route) simultaneously in a single demand model. In contrast, sequential model assumes that the individual choices are made sequentially in some order. Thirdly, the existing demand models may differ in terms of economic theories. According to the economic theories and the research attributes, the microeconomic and macroeconomic models can be identified. Fourthly, based on the difference of modeling techniques and structures, the demand models may classified into the linear model, the log-linear model, the logit model, the translog demand models, and the mixed structure models. Figure 2 shows how demand models can be classified based on different criteria. Since the identification of aggregate and disaggregate outlines the characteristics of various models, in this section the exploration of classification of model families is based on the analysis of aggregate and disaggregate models.

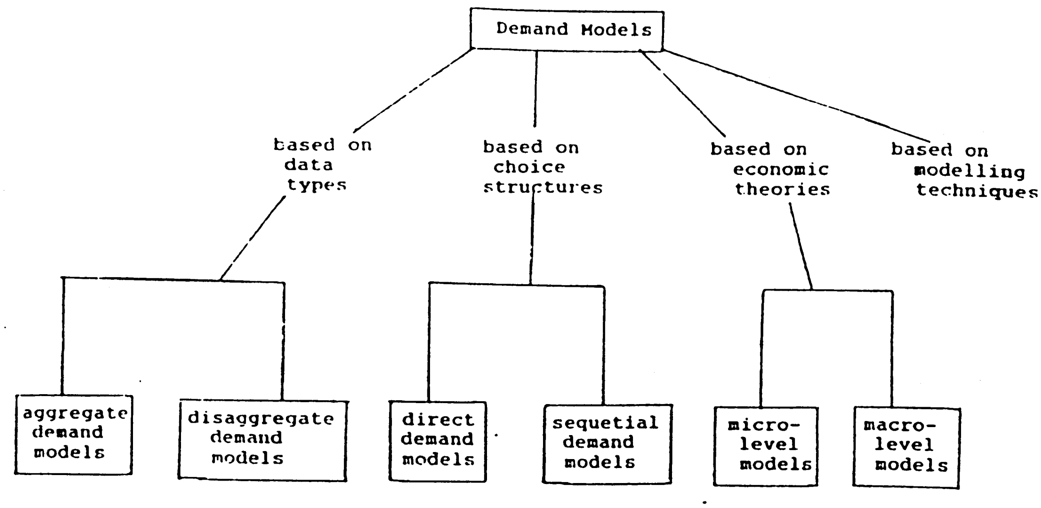

Figure 2 A Framework for Analyzing Demand Models

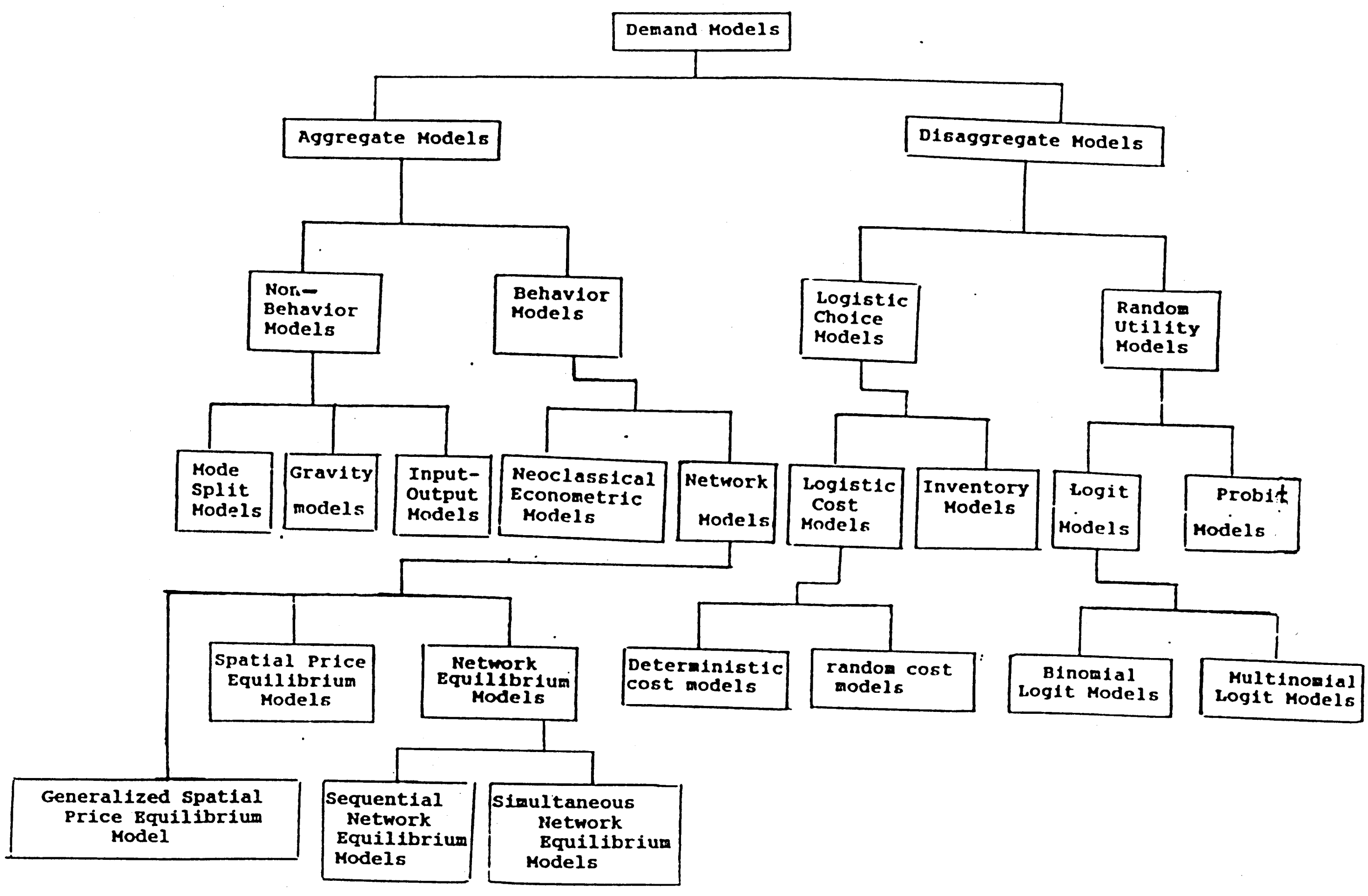

Figure 3 Classification of Freight Transportation Demand Models

Figure 3 shows freight transportation demand model systems. The classification of intercity freight transportation models is based on the following analyses. On the side of aggregate demand models, the various models can further be distinguished by either behavior or non-behavior models. Using behavior characteristics as a criterion to study the classification of various models is very helpful since it describes whether a model can be employed to simulate the shippers and the carriers' choices and their interrelationships. Within the categories of behavioral and non-behavioral aggregate demand models, a further classification can be obtained in terms of the theories and approaches. On non-behavior side, according to Newton's law of gravity, the gravity type models can be easily distinguished. The gravity-type models are popular due to easy interpretation of framework and estimation of model parameters. The gravity models dominated the conceptual framework of intercity freight transportation demand forecasting in the 1960s and the early of 1970s. While based on the macroeconomic theory, the input-output model becomes a major member of aggregate demand model family. The input-out model is non-behavior and aggregate in nature and the model is usually used for evaluating alternative government strategies of freight distribution in national wide and applied to find optimum plans to balance the nonhomogeneous separation of production and consumption of cities and regions. Within the category of aggregate models another important family is model split models. Since the behaviors of agents involving in freight transportation system are ignored by early aggregate modal split models, the title of non-behavioral aggregate modal split model may be suitable to describe this model family. The early modal split models are commonly employed to predict the amount of commodities to be transported under a given set of modes.

The aggregate logit model is a major member within the family of modal split models and is generally used to examine the sensitivity of variation of market shares of alternative freight transport modes to the changes in regulatory or managerial control variables, such as relative price and relative quality attributes. Examples of using aggregate logit models are Perle (1964), Quandt and Baumol (1966), McLynn and Watkins (1967), Kullman (1973), Boyer (1977), and levin (1978).

On the side of the behavior models, one major family within the category of neoclassical econometric models is the translog demand model. The model is derived from the neoclassical demand theories and has been applied to freight demand analysis since the mid-1970s. The model is either derived from the 'flexible' utility (for consumer demands) or from the production (for input demands) function. Based on the utility or production/cost function, the translog model is consistent with the neoclassical theory of consumption or production and allows for free variation of the elasticities of substitution between transportation modes and other variables. Examples of the models included in this family are Diewert (1973), Oum (1979), Harmatuck (1979 and 1981) Friedlaender and Spady (1980 and 1981) and Oum and Gillen (1983 and 1984), Friedlaender and Wang (1983), Caves, Christensen, and Tretheway (1984).

Recently, the family of network models plays more and more important role for studying the distribution and assignment of commodity flows. However, due to the difficulty of handling large-scale network problems, the aggregated network models which could provide a way of mitigating computational difficulties are preferred by transportation planners. Therefore, most network optimization models are usually aggregate in nature. In addition, since the network model does has capability to capture the behaviors of the shippers and the carriers, the network optimization models are recognized as one important family in the category of aggregate behavioral models. Within the family of network optimization models, the three major members, the spatial price equilibrium models, the network equilibrium models, and the generalized spatial price equilibrium model, are identified according to different objectives of model formulation. Examples of using network models are Roberts (1966), Kresge and Roberts (1971), Takayama and Judge (1973), Peterson and Fullerton (1975), Kornhauser (1979, 1982), Ebeling (1981), Chang (1980), Friesz,et al. (1981), Gottfried (1983), Hark and Friesz (1986), Hark (1987).

On the side of disaggregate demand models, the most popular used models are logistic choice models and random utility models. The logistic choice models can still be divided into logistic cost models and inventory models according to different design objectives. Within the family of logistic cost models, due to the difference of function form, the deterministic cost models and random cost models can be further identified. While within the family of inventory models, the single-item and multi-item inventory models can be further differentiated. Another major family in the category of disaggregate models is the random utility models. In accordance with the different assumptions of distribution of random variables in utility function and the difference of model structures, the models can be distinguished by disaggregate logit models and the probit models. The disaggregate logit models are very popular due to the intuitive and theoretical rationale. The model is derived from the utility maximizing theory and a random utility function is defined over price and attribute space. The two major members in this family are the binomial logit models and the multinormial logit model. The disaggregate choice models, recently, have been widely applied to predicate the movement of intercity freight, because the shipper or the receiver's optimum choices of minimizing its total purchase and logistics costs over all of the input materials, the size of shipment, and the modes of transport, can be captured by various choice models. The examples of the applications of choice models are Hartwig and Linton (1974), Waston et al.(1974), Roberts (1976), Roberts et al.(1977), Allen et al. (1977), Levin (1978, 1981), Daughety (1979), Winston (1979, 1981a, 1981b), Roberts and Change (1980, 1981), Heshemian (1981), McFadden and Winston (1981), Benabi (1984), Sargious and Tam (1985), McFadden et al. (1985), and Wilson et al. (1986).

6. Conclusions

From the analysis of the previous sections, it is clear that many theories and methods applied for freight transportation demand analysis were borrowed from other research areas, such as microeconomics, macroeconomics, social science, and physics, etc.. Their adequacies for freight transportation demand analysis remain to be fully investigated. Therefore, the models developed on these theories and methods need not only to be analyzed in small sample test but also need to be examined in practice. Although it is difficult to design a demand model to capture all factors, a successful freight transportation demand model is required to be able to sort out the complicated interrelationships of the behaviors of the agents involved in freight transportation demand and has the properties of sensitivity, forecasting ability, simplicity, and transferability. Based on the above analysis, the further research topics that may be especially useful are organized into the following aspects.

1) Study of the behaviors of agents The universality of the regularities in the behavior of producers, shippers, carriers, and their interactions should be extensively examined and analyzed. The clear criteria and approaches for capturing and testing these behaviors in demand models should be carefully examined.

2) Dynamic modeling of the choice of agents Most of existing freight transportation demand models are static in nature because the behavior characteristics of transportation user are assumed static during the process of freight movement. However, it is known that decisions are usually made in a dynamic environment since decision makers constantly learn and change preference in each choice situation from place to place and from time to time. In order to know how agents response to the changes in the transportation regulations, services, and related environments, the development of dynamic choice models in which agents would make their future choices in lights of past experiences is required for transportation planners.

3) Analysis of links between different approaches Because the study of the links between different approaches will strengthen research theory and method for analyzing overall realism of the predictive freight transportation models, the research work of the effectiveness of combination of several approaches to demand analysis is necessary and may have significant meaning.

4) Introduction of new theories and approaches New methodologies,

unconventional approaches, and improved theories from other research fields (e.g., economics, operation research, mathematics, management science, etc.) should be continued to be expanded to the field of freight transportation demand research and model systems. The introduction of more advanced theories and approaches will lead to the further development of sophisticated demand models for analyzing freight transportation system.

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