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LOGISTICS CONCEPTS IN FREIGHT TRANSPORTATION MODELING

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ABSTRACT

The purpose of this paper is to review logistics concepts used in macro freight transportation modeling by various planning agencies at the national, state and city level. The chronological development of freight modeling endeavors are studied here and the logistics component incorporated in the modeling is identified. The key modeling tools are identified and analyzed to identify the efficacy of the model, ease of use, and data required to implement the model. The conclusion was that European freight models were more developed than North American freight models. The tools most widely used are the aggregate-disaggregate-aggregate model, input-output model, artificial neural network model, matrix estimation method and PCOD model. This paper will give transportation modelers a better idea of the freight modeling tools available.

INTRODUCTION

Macro freight modeling is an integral part of transportation planning, undertaken by government agencies and metropolitan organizations to estimate present and future transportation demand. Freight modeling has undergone major developments and transformations since its inception to suit the dynamic nature of transport modeling. A significant amount of knowledge has been added over time with the goal of connecting the various stages of freight transport modeling including: production and consumption, trade (sales and sourcing), logistics, transport, and network services (Tavasszy, 2006). Traditionally, the four stages, in passenger transport modeling have been linked to research and studies in freight modeling. It is generally observed that a significant number of freight models, both regional and national, fail to incorporate real life logistics dimensions (e.g. distribution centers) into their framework (Jong et al., 2005). The term logistics includes all activities related to planning and implementing the movement of raw materials, inventory and finished goods from origin to final destination. The logistics decision making process includes inventory control, material handling, ordering processes, plant and warehouse selection, mode choice, and warehouse and storage decisions. It is understood that all these varied decision can be taken in isolation or may be related to each other. A review of existing literature on freight modeling found significant research on mode choice of freight shipments, but not much research on selections of distribution center, warehouse, and in some cases intermodal terminals. Business entities' logistics decisions are dynamic and constantly updated based on input from external agents, including: transportation rates of competing modes, change in demand, price fluctuation, availability of raw materials, and numerous other factors in the business environment.

Observed increases in world population and rapid globalization have fueled growth in U.S. trade from $889 billion to $3.4 trillion between 1990 and 2008 (BTS, 2010). This growth in trade is reflected by increased volumes of freight at U.S. freight gateways and corresponding domestic connections. Considering the economic growth witnessed in recent years, it is unreasonable to model future freight demand in a satisfactory manner without incorporating logistics dimensions in the freight model (Jin et al., 2005). Freight forecasting models, indeed, need to incorporate logistics factors in the modeling process. However, a review of existing research revealed that most of the models need considerable development in this area. It is widely understood that incorporating some of these logistics decisions in the modeling framework can be extremely challenging given that these factors are specific to individual business entities. The data requirement can be immense even if a small sample size is used in a study. In order to implement a logistics model, there is a need to develop a much higher resolution data base for production, attraction, distribution and storage location of individual commodities or commodity groups. The logistics model will not only determine the origin, destination, and intermediaries, but it will also identify the mode of transport most suitable for moving the freight. In urban freight models, mode choice is not a significant issue since the majority of the freight moves by trucks.

Based on data availability and degree of accuracy required, different researchers have used different mathematical models to predict freight flow. This paper aims to present a holistic view of the importance of incorporating logistics into the freight modeling process. This is done by reviewing existing logistics concepts, followed by reviewing existing freight logistics models in Europe and the United States. Special attention is given to identify mathematical models employed to incorporate logistics concepts into freight modeling. We have also looked into data requirements in each of the freight models that do incorporate logistics dimensions.

FREIGHT MODELING CONCEPTS AND EMERGING ISSUES

Commodity and Trip Based Models

Freight modeling, can be broadly classified into two categories namely trip-based and commodity-based models (Holguin-Veras and Thorson, 2003). In trip-based models truck trips are estimated from observed parameters like the number of employees in an organization, floor area of the organization, sales volume and other related factors. In the trip-based approach, commodities produced and consumed are not considered for estimation purpose. The commodity-based approach estimates the quantity of a commodity that is moved between each origin-destination (OD) pair. In the final stage of the modeling, the commodity flows are converted into truck trips, based on the type of vehicle used and the corresponding payload of those vehicles. Some modelers prefer the trip based model, because the trip based model needs fewer data elements compared to the commodity based model. The data needed for trip based modeling is obtained from a survey of truck trips. The main disadvantage of the trip based model is its disconnection with the economy. This disconnection makes it difficult to forecast, based on economic growth.

Commodity based modeling can forecast truck traffic based on economic growth and other parameters of production and consumption of goods and services. The principal drawback of commodity based modeling is its inability to capture the behavioral content of freight flows. The other disadvantage is the detailed input-output data requirements to model the flows.

Logistics Cost Optimization and Simulation Models

There are a number of logistics models which can be used for cost optimization to estimate freight flows. One of these classes of model is known as the economic order quantity (EOQ) model. In this model the optimal lot size is determined, which in turn will affect the type of vehicle used for delivery as well as the number of annual shipments. The EOQ model estimates the optimal order quantity as $Q = \sqrt{2DS/hC}$ where Q is the optimal lot size, D is the annual demand; S is the ordering cost per lot; h is holding cost; and C is the cost per item. There can be a number of modifications of this basic EOQ model based on specific business scenarios. This model can be modified for number of items included in one order. The order frequency in this case is defined as $n = \sqrt{(D_1C_1h + D_2C_2h + \cdots\cdots + D_nC_nh)/2S}$ where D_n is the demand of n^{th} item, and C_n is the cost of n^{th} item. The other modification of the base EOQ model would be to include discounted cost based on the lot size. There are some heuristics methods available to estimate the optimal quantity based on the discounted price. This model can be further improved by incorporating uncertainty in the demand, and then solving the stochastic model to estimate Q.

Another important concept in logistics and freight modeling is that of network design. The network design is formulated based on the objective of maximizing customers' satisfaction and firms' competitive position. These models determine location of logistics facilities including production centers, warehouses, and distribution centers. This model also estimates the capacity of each of the locations. The choice between available transportation services is determined by the logistics requirements such as the availability of vehicles, warehouses, consolidation, and terminal facilities. Boerkamps et al., (2000) described the transportation systems as a collection of supply chain linkages. According to the authors, a supply chain linkage is a trade relationship between the shipper and the receiver in a network of interconnected linkages between raw material suppliers, producers, trading companies, retailers, and end users. Supply chain linkages may involve a number of distribution channels, for instance direct distribution (shipper to receiver) or intermodal distribution (shipper to intermodal facility, intermodal facility to receiver). See Figure 1.

We present here a simple transshipment model which can be used to determine optimal shipping patterns and shipment sizes for networks with a consolidation terminal and cost functions. A standard model formulation of such a transshipment model is given below.

$$
\begin{aligned}
Min \sum_i\sum_j\sum_m X_{ijm}\times D_{ij}\times C_{ijm} + \sum_i\sum_k\sum_m X_{ikm}\times D_{ik}\times C_{ikm} + \sum_j\sum_k\sum_m X_{jkm}\times D_{jk}\times C_{jkm} + \\
\sum_j\sum_k\sum_m X_{jkm}\times HC_{im} + \sum_j\sum_k\sum_m X_{jkm}\times HC_{im} + \sum_j\sum_k\sum_m X_{jkm}\times HC_{jm} + \\
\sum_j\sum_k\sum_m X_{jkm}\times HC_{jm} + \sum_i\sum_k\sum_m X_{ikm}\times HC_{km} + \sum_j\sum_k\sum_m X_{jkm}\times HC_{km}
\end{aligned}
$$

Subject to:

$$
\begin{aligned}
& P_{im} - \sum_k X_{ikm} - \sum_j X_{ijm} \geq 0; \forall i, m \\
& \sum_i X_{ikm} - \sum_j X_{jkm} + A_{km} \geq 0; \forall i, m \\
& \sum_i \sum_m X_{ijm} - CAP_j \leq 0; \forall j \\
& \sum_i X_{ijm} - \sum_k X_{jkm} \geq 0; \forall j, m \\
& X_{ijm}, X_{ikm}, X_{jkm} \geq 0; \forall i, j, k, m
\end{aligned}
$$

Indices, decision variables, and parameters used in the model formulation are presented in Table 1. The model objective function (1.1) minimizes the sum of total transshipment and handling costs in a given freight network involving production, consumption and intermediate facilities. The model output determines the optimal shipping patterns and shipment sizes for the networks and the number and location of intermediate facilities to operate.
C_{ijm}, C_{ikm} *and* C_{jkm}, which are the unit cost of shipment for different legs of the shipment. These depend on the type of shipment and whether it is truck load (TL), less than truck load

FIGURE 1
LIKELY RATIONALE BEHIND THE EVOLUTION OF FREIGHT LOGISTICS MODELING

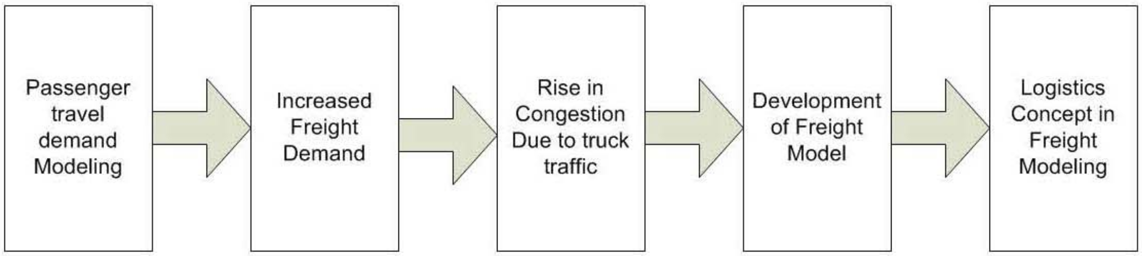

TABLE 1
DESCRIPTION FOR TRANSSHIPMENT MODEL FORMULATION

<u>Indices:</u>
m: type of goods
i: production location
j: intermediate facilities
k: consumption location
<u>Decision Variables:</u>
X_{ijm}: unit of type m goods transshipped from production point i to intermediate facility j
X_{ikm}: unit of type m goods transshipped from production point i to consumption point k
X_{jkm}: unit of type m goods transshipped from intermediate facility j to consumption point k
<u>Parameters:</u>
D_{ij}: distance between production point i and intermediate facility j
D_{ik}: distance between production point i and consumption point k
D_{jk}: distance between intermediate facility j and consumption point k
C_{ijm}: unit cost of shipping type m goods from production point i to intermediate facility j
C_{ikm}: unit cost of shipping type m goods from production point i to consumption point k
C_{jkm}: unit cost of shipping type m goods from intermediate facility j to consumption point k
HC_{im}: unit cost of handling (loading/unloading) type m goods at production point i
HC_{jm}: unit cost of handling (loading/unloading) type m goods at intermediate facility j
HC_{km}: unit cost of handling (loading/unloading) type m goods at consumption point k
P_{im}: production of type m goods at production point i
A_{km}: consumption of type m goods at consumption point k
CAP_j: transshipment capacity of intermediate facility j

(LTL) or small package shipment. For TL shipment the truck configuration will have a big impact on the cost. Some of these rates are available from published rate sources for different shipment types. More specific information is obtained by surveying shippers and carriers. In many instances, there is rate negotiation between shippers and carriers, and most often it is difficult to get these negotiated rates due to issues related to confidentiality.

Constraint sets (1.2) and (1.3) are the production and attraction constraints, which ensure that demand at consumption points are satisfied with the supply generated at production points. Constraint (1.4) is the capacity constraint for intermediate facilities, which limits the amount of total inflow to the intermediate facilities; ensuring available transshipment capacities are not exceeded. Constraint set (1.5) is the flow conservation constraints in the transshipment network, which ensures that the sum of inflow to any intermediate facility is equal to the sum of the outflow from that intermediate facility. Finally, the nature of decision variables is defined in (1.6); all decision variables are non-negative real number values. The proposed model can easily be improved by introducing the following system design aspects to the model formulation: inventory, modes of transportation, shipment size, shipment unit, and multiple planning periods.

Many distribution networks are influenced by third-party logistics (3PL) providers. A 3PL is a third party company that manages the delivery of logistics services (Hertz and Alfredsson, 2003). More and more firms are outsourcing their logistics activities to 3PL companies. Tian et al. (2009) have undertaken research to understand the relationship between a 3PL and its customer firms. This research found that 3PL's significantly improve the logistics process of customer firms. Distribution network design by a shipper differs considerably from a network design by 3PL service providers. 3PL service providers would consolidate shipments from suppliers and direct it to manufacturing plants based on the available consolidation center of the 3PL providers (So *el al,* 2007).

The other concept, which is becoming increasingly important, is reverse logistics. Reverse logistics has a shorter product lifecycle and also a more demanding customer (Daugherty *et al*., 2001). Reverse logistics needs an efficient network design to minimize the cost of transporting returned goods under new sets of supply, demand and capacity constraints. This network design is much more complex, because of the higher degree of uncertainty (Lieckens and Vandaele, 2007).

Two other concepts which are increasingly becoming important in logistics network design are "lean" supply chains and "green" supply chains. Lean supply chains aim at reducing waste and elimination of non-value added activities which includes time, labor, equipment, and inventory (Corbett and Klassen, 2006). Green supply chain strategy tries to minimize the negative impact of supply chains on the environment. Participation of suppliers, customers; and internal operations and processes managers, is required to make the supply chain green (Corbett and Klassen, 2006; Mollenkopf, 2010).

LITERATURE REVIEW OF MACRO FREIGHT LOGISTICS MODELS

Chronological Development of Freight Logistics Models

Tavasszy (2006) emphasized the integration of logistics factors into freight models. He traced early developments in the Netherlands in the first half of the 1990s, which took more than a decade before being recognized elsewhere. Tavasszy also indicated that development in freight logistics in general can be directly linked to local priorities in freight policy. He also points out that freight modeling has taken different directions in different countries and continents. For example, freight modeling development in Europe has taken a different course compared to that of the U.S. The chronological development of various freight logistics models are shown in Table 2.

TABLE 2
CHRONOLOGICAL DEVELOPMENTS OF LOGISTICS IN FREIGHT MODELING

Date	Mode / Levels	Study	Description	Country of Origin
1990	National	LMS	Joint assignment of passenger and freight vehicles	Netherlands
1992	National	TEM	Forecasting model based on the observed data of 1992	Netherlands
1996	National	SISD	Disaggregate RP mode choice models and assignments	Italy
1996	National	WIVER	Reproduce vehicle flows on transport infrastructure	Germany
1997	National	NEMO	Considers rail, road, and sea simultaneously. Simulates competition between modes	Norway
1997	International	NEAC	Models the distribution between production and attraction on basis of value added per sector	Europe
1998	National	SMILE	Routing of freight flows via distribution centers	Netherlands
1998	International	STEMM	Methodology for modeling multi-modal chains for passenger and freight transport	Europe
1999	National	GOODTRIP	Connects activities of consumers, distribution centers and producers	Netherlands
1999	International	STEEDS	Output of model is decision support system	Europe
2000	International	SLAM	Supply path choices	Europe
2000	Regional	WFTM	Uses a multimodal network assignment; implemented in a NODUS software	Belgium
2001	National	SAMGODS	Used to evaluate modal shifts, uses multi-sector input/output tables for the country	SWEDEN
2001	National	BVWP	Works on levels of aggregated flows	Germany
2002	International	SCENES	Drivers of Transport demand, External and policy scenarios, Infrastructure and pricing scenarios	Europe
2002	International	EUFRANET	Rail scenarios are projected for 2020 horizon	France, Germany, Netherlands
2004	National	PCOD	Depicts interrelationship between spatial distribution of freight	Denmark
2005	International	ASTRA	Aggregate model to describe overall economic activity	Europe
2005	International	EUNET2.0	Logistics using spatial input-output modeling	United Kingdom
2005	Regional /Urban	Cube Cargo	Simulate regional and urban truck/freight movements	USA
2006	Urban	INTERLOG	Rule based freight transport simulation system; traffic conditions and regulatory measure	Germany
2007	Urban	Tokyo Model	Commercial traffic in Tokyo metro area	Japan
2007	Urban	Calgary Model	Reproduce commercial vehicle flows on transportation infrastructure	Canada
2007	National	ADA	Model national freight traffic	Germany
2009	National	SYNTRADE	Focused on Food retailing sector; Furness Method, Monte-Carlo Simulation, Gravity Model, Optimization Model	Germany

European Macro Freight Models

Traditionally most freight models were developed in Europe, probably due to the interconnectivity of European nations and the need to accurately portray rising freight costs associated with shipping freight within and across national borders. Some prominent and widely used European freight models are:

SAMGODS Model

SAMGODS was developed by the Swedish Institute for Transport and Communications Analysis (SIKA) in 2001. The Aggregate-Disaggregate-Aggregate (ADA) modeling tool in SAMGODS is also used in NEMO, which is the freight model developed for Norway. NEMO and SAMGODS incorporated logistics aspects into the freight modeling process (Jong *et al*., 2005).

SMILE Model

SMILE (Strategic Model for Integrated Logistics and Evaluations), originally initiated in 1998 in the Netherlands, and was the initial aggregate freight model developed to estimate freight flows via distribution centers using discrete choice modeling (Tavasszy *et al*., 1998). SMILE is applied on a national scale, with the principal objective of modeling future freight flows on the transport network by precisely modeling a path from one region to the other (Friedrich and Liedtke 2009). The path of freight flow and mode choice is analyzed jointly based on logistics costs and warehouse costs. Another model similar to the SMILE is the SLAM (Spatial Logistics Appended Module), which is a European level transport model, defining supply path choices similar to that in SMILE.

GOODTRIP Model

The GOODTRIP model closely followed the development of the SMILE model and has the potential of determining the costs, performance, and impacts of long term transportation policy making and implementation (Tavasszy, 2006). GOODTRIP was initially intended to assess the general logistical performance and environmental impacts of alternatives policies. This later narrowed down to the food, retail, and bookstores sector because of potentially larger differences in distribution structure of various products and consumer behavior (Boerkamps and Binsbergen 1999). As a disaggregate model, GOODTRIP aimed at evaluating changes in supply chain networks, consumption and distribution patterns, delivery requirements, mode choices, and environmental impacts. The GOODTRIP model is different from the SMILE model in two ways (Yang *et al*., 2009). In the GOODTRIP model, activities and vehicle tours are estimated from land use. In the case of the SMILE model, activities and vehicle flows are generated from commodity flows.

EUNET2.0 Model

EUNET2.0 is a regional economic and freight logistics model that was developed in 2003 as a pilot model, to enhance the understanding of existing and ongoing research in logistics using spatial input-output modeling in the United Kingdom (Jin *et al*., 2005). In this model, freight flow is segmented into a number of logistics stages, according to commodity type.

A significant number of origin-destination (O-D) matrices are divided into commodity type, and various distribution phases, which include distribution centers, ports and local depots. This model captured the effect of logistics centers and the national economy on freight movement (Jin *et al.*, 2005).

PCOD Model

Holmblad (2004 proposed the PCOD freight transport model. This PCOD model illustrates the interrelationship between the spatial distribution of freight and transportation patterns emanating from an existing transport network. The PCOD model converts the PC matrix into an O-D matrix. The PC matrix contains information on amount of goods produced at the production zone and the amount of goods consumed at the consumption point. Logistics nodes are introduced in between these terminal points to model the actual flow and develop the O-D matrix. With the incorporation of indirect transport, Holmblad (2004) predicted that the transport of goods through logistics nodes would be more cost efficient, owing to the fact that logistics operators would have the choice of scheduling their transport needs to optimize existing transportation resources.

North American Macro Freight Models

In general, the evolution of freight modeling in the United States can closely be linked to passenger travel modeling. A significant number of models developed are simplistic adaptations of urban travel demand models. Hamburg (1958) indicated that attempts to formulate truck freight models can be traced back to Detroit. Subsequent initiatives have been made to adapt passenger travel forecasts to truck modeling. Some metropolitan authorities and states have customarily overlooked freight models or have used rudimentary estimates of truck movement in their modeling process (RAND Europe et al. 2002). However, in recent years, there has been a shift towards more elaborate models with improved data granularity (e.g. commodity flow survey). The United States has two distinct freight models: commodity flow models and truck flow models developed at the urban, state and national levels (RAND Europe et al. 2002). The dichotomies between these two models are attributed to the difference in priorities at each level (Tavasszy, 2006). Presently, there is lack of information about the number of existing truck models in the United States. It is general observation that most freight models do not represent the existing strategic link between the economy and the transportation network (RAND Europe et al. 2002).

Some of the most promising freight models in the United States are the Seattle FASTrucks Mode, the New York City Best Practice Model, the Oregon TLUMIP Commercial Travel Model, and the Los Angeles County Metropolitan Transportation Authority (MTA) freight transportation planning model. The vast majority of U.S. models are based on the four-stage passenger modeling framework and lack logistics dimensions. The MTA model for Los Angeles is promising in terms of incorporation of logistics factors and does so by applying methodologies similar to that in SMILE and the GOODTRIP model (Fischer *et al.*, 2005).

REVIEW AND ANALYSIS OF MODEL TYPES

Aggregate-Disaggregate-Aggregate Model

Aggregate-Disaggregate-Aggregate models involve a number of demand matrices, which are specific for a particular commodity, and show the quantity of goods transported from one zone to another. As discussed by Ben Akiva et al. (2008), aggregate models tend to be based on cost minimization behavior of firms, while disaggregate models include more detailed policy-relevant variables for firms' decision making. In practice, disaggregate models have several drawbacks. One of these is the need for more detailed data, which is difficult to generate because of cost and confidentiality (Winston, 1983 and Oum, 1989). Although difficult in practice, disaggregate models produce more accurate individual mode choice forecasts by representing the cause and effect relationships in firms' decision making processes. However, aggregate and disaggregate approaches should be considered complementary, not competing (Ben Akiva et al. 2008). Integrated aggregate-disaggregate modeling approaches benefit from aggregate data when representing collective behavior, and from disaggregating when the data represents the behavior of individual decision making processes (Ben Akiva et al. 2008 and Samimi et al. 2009).

The disaggregate logistics model is undertaken in a series of steps. The first step is the disaggregation of flows from one firm to another firm. The second step is the logistics decisions by firms, and finally aggregating freight to O-D flows for network assignment (Jong et al. 2005). The logistics model helps to determine shipment size and transport chain (e.g. mode, vehicle and terminal types, and loading unit utilized). The ultimate decision making process at the firm level is the minimization of total logistics costs. The total yearly logistics costs are estimated by the equation below

$$G_{rskmnql}=O_{kq}+T_{rskql}+D_{k}+Y_{rskl}+I_{kg}+K_{kq}+Z_{rskq}$$

Where, ***G*** is total yearly logistics costs; ***O*** is the order cost; ***T*** is the transport, consolidation and distribution costs, ***D*** is cost of deterioration during the hauling process; ***Y*** is capital cost of goods in transit; ***I*** is inventory costs; ***K*** is cost of inventory and ***Z*** is the stock out costs.

Input-Output Models

Input-output models provide an overview of the flow of goods and services to analyze the economic progress and show intermediate transactions between producers and customers. Input-output tables show goods and services produced in a year through domestic production, imports, consumption of goods by customers, and exports. The demand generated by domestic industries and imports is disaggregated by different industries. Input-output coefficients represent the amount of input required to generate one unit of output necessary to satisfy the demand generated by domestic industries and imports. Input-output models can be used to represent single-region and multi-region commodity flows. According to Ben-Akiva et al. (2008), multi-region input-output models usually perform better than single-region input-output flows. Ben-Akiva *et al*., (2008) pointed to major multi-region input-output models undertaken by Chenery (1953), Moses (1955), Leontief (1936), Bon (1984) and Cascetta (2001). The main difference among these models is the way in which the effects of technical coefficients and trade flow coefficients are estimated in the modeling structure. In freight demand modeling, changes in transportation infrastructure can directly affect the amount of transportation service available and can affect trade flows. Therefore, changes in freight movement networks have inevitable impacts on input-output coefficients.

Using Leontief's Input-Output model, a generalized form of the EUNET2.0 model shows total consumption, demand, and the total amount of a given commodity ***m*** that is used for producing commodities as

$$D^{m} = Y^{mo} + \sum_{n} a^{mn} X^{n} \; \forall m$$

Where:
D^m is total consumption of commodity m, Y^{mo} is the quantity of final demand of commodity m X^n , is the quantity of production of commodity m and, $\sum_{n} a^{mn} X^{n}$ is the quantity of commodity m that is used for producing all commodity n.

Artificial Neural Networks

The artificial neural network (ANN) is a type of network structure in which the nodes are the "artificial neurons" and the edges connecting these nodes are the "synapses". In the ANN model the computation is done replicating the way the brain handles information. The input and the output of the computational information process is received and sent via synapses from and to the other artificial neurons, respectively. The order of input and output transfers is performed according to the information processing state of the artificial neuron in the artificial neuron network. The information processing structures of artificial neurons may vary; artificial neurons can be designed to perform very simple operations (i.e. adding to input values) or very complex operations (i.e. there can be sub-artificial neuron networks within an artificial neuron). It is also possible to group artificial neurons in different layers. In such a case, artificial neurons are typically organized in three layers: the input layer which accepts the model inputs; the output layer which provides the final model output; and the hidden layer which functions as the computational information processing structure (Bilegan et al. 2007).

There has been a variety of artificial neural network applications in the area of transportation. A comprehensive review of artificial neural network applications in transportation is presented by Dougherty (1995). It is observed that in the area of freight demand modeling, the use of artificial neural networks is relatively new. According to Bilegan et al., (2007), artificial neural network applications in freight demand modeling have potential to improve the performance of predictive models.

Matrix Estimation Methods

Production-consumption (P-C) and origin-destination (O-D) matrices are the basic trip matrices for freight planning and management. The P-C matrix represents the economic trade patterns between zone pairs; primary producers to final customers. The origin-destination (O-D) matrix represents the actual physical movements in the transportation infrastructure, from production zones to consumption zones. In short, the O-D matrix represents the actual freight movement of the P-C matrix (Williams and Raha 2002).

There is a compromise between model complexity and data accuracy in choosing an adequate representation of transportation demand. The reason for the compromise is that the detailed description of trip data, between origin and destination pairs, is not always available. The feasibility of collecting trip data, including the origin, the destination, all intermediate stops (warehouses, intermodal facilities), the exact time, the route, and the purpose of the trip is a challenging task. Even if the data collection process is feasible, the amount of information would be unmanageable. Therefore, reasonable representation of demand should be somewhere in between these two extremes (Williams and Raha 2002).

The O-D and P-C matrices are reproduced data. The following are the important points to consider when generating O-D matrices from original data sources (Williams and Raha 2002):

- All of the available observed data resources like prior matrix and traffic counts should be used efficiently.
- Data from different sources like different sampling fractions and inaccurate data may not be consistent.
- Use of data sources can be weighted based on the data source reliability, accuracy of measurements, and sampling errors.
- Matrix estimation procedures should consider trends in different commodity categories, economic and industry trends
- Future changes in transportation infrastructure and transportation costs should be considered including logistics cost.

Our review indicates that a critical improvement has taken place in freight modeling is the inclusion of logistics dimensions. In the next section of this article we present a discussion of the mathematical tools used to incorporate logistics aspect in freight models.

PCOD Models

The principal objective behind the inclusion of distribution centers in a supply chain or goods flow network is to reduce overall transportation costs. The PCOD model proposed by Holmblad (2004) is an effort to model freight flow through a network using distribution and consolidation centers. Certain assumptions are required to introduce logistics in transforming the P-C matrix into an O-D matrix. This is evidenced in Holmblad (2004) who indicated that traditionally, due to potential complexities, logistics structure in the production-to-consumer chain is generally approximated. Contrary to existing and most recent advances in transport logistics models, which undertake the bottom up modeling approach with an extensive treatment of modes and networks, the PCOD modeling approach applies a top to bottom modeling framework. This is characterized by meso-economic, aggregate transport logistics modeling, using regional transport centers with transport decision making at the micro and macro levels (Holmblad 2004). Holmblad (2004) indicated that the PCOD model has two principal features that make it suitable for freight modeling. In general, the modeling of freight movement in the transport system can be undertaken using a heuristic technique, in which the unit cost of transport is dependent on the volume of transport.

First, as previously mentioned, the PCOD model follows a cost minimization approach using the heuristics framework. It converts the regional trade flow to regional transport flow, thereby providing better modeling results relative to a macroscopic approach. Second, by representing the transport system and network by a limited number of parameters, the PCOD model formulation provides a simplistic and easy to understand approach to freight transport using distribution centers. To begin with, the PCOD model divides the general area of interest into zones that have both production output (P_r) in zone r and final consumption (C_s) in zone s. This main level of the model building process is referred to as the P-C land or level 1.

The second level, described as distribution-consumption (D-C) land, is characterized as a transport only zone with no likely production or consumption. Transport is not restricted within D-C land, but in P-C land it can be direct transport only ($l=r$ *and* $m=s$). The connection between P-C and D-C land can be denoted by a matrix element $PCOD^w_{rslm}$, which is a depiction of transport between the zone r and the zone s (PC_{rs}) that constitutes the total transport OD^w_{lm} from l to m. The matrix element representing the connection between P-C and D-C land ($PCOD^w_{rslm}$) corresponds to transport from zone l to zone m. The matrix representing the connection between levels in the PCOD model is as follows

$PC_{rs}: (PCOD^w_{rslm})$, where

$$PCOD^w_{rslm}=PC_{rs} \text{ or } PCOD^w_{rslm} = 0$$

The entire system is formulated as a system of linear equations; however, a method at arriving at the cost of transportation and handling at the distribution centers is necessary so as to minimize the system costs.

CONCLUSIONS

This paper illustrates that freight modeling efforts are not fully realized, without considering logistics components in the modeling process. The majority of freight models have closely followed traditional four stage passenger travel demand models. The need to improve and incorporate logistics concepts is understood by transportation modelers both in Europe and the United States, but incorporation of these dimensions into models has been slow. This slow development might be explained partly by the lack of data needed to incorporate logistics elements in freight models, and partly by the inability of existing modeling tools to incorporate these dimensions. In this paper we have traced the emergence of freight models in different parts of the world and the chronological order of this development. We have focused on the mathematical tools used in these models as well. In many modeling endeavors, the key obstacle is to adapt the right mathematical tool. This paper should assist modelers in adapting the right tool based on the modeling objectives.

We have categorized the modeling endeavor into European freight models and North American freight models. We suggest that European freight models seem to be more developed, as far as inclusion of logistics aspects in freight modeling is concerned. We have identified that *SAMGODS, SMILE, GOODTRIP, EUNET2.0, PCOD* are pioneering freight models which have incorporated logistics dimensions into the modeling process. The modeling technique used in many of these freight models are varied, but the prime modeling tools used are aggregate-disaggregate-aggregate models, input-output models, artificial neural network models, matrix estimation methods and the PCOD model. Based on the objectives and data availability, these modeling tools are implemented and various additions and alternations are undertaken to arrive at more realistic results for successful implementation.

Logistics decisions, in a business entity, are dynamic and are reshaped constantly by changing business needs. These decisions play major roles in the direction of freight movement within and beyond the domestic boundaries of a country. Some of the logistics concepts like reverse logistics; 3PL and green supply chains were not observed in most of the logistics concepts introduced to macro freight models. The learning curve for freight modeling is improving, and it can be anticipated that newer concepts in logistics will be adapted in freight modeling. Finally, it should be recognized that more work can be done in this area.

REFERENCES

Ben Akiva, M., Meersman, H., and Voorde de, E. V. (2008), *Recent Developments in Transport Modeling: Lessons for the Freight Sector*, Emerald, Bingley.

Bilegan, I.-C., Crainic, T.G., and Gendreau, M. (2007), "Forecasting Freight Demand At Intermodal Terminals Using Neural Networks: An Integrated Framework," The Sixth Triennial Symposium on Transportation Analysis. Phuket Island, Thailand.

Boerkamps, J, and Binsbergen, van. A. (1999), "GOOTRIP- A New Approach for Modeling and Evaluation of Urban Goods Distribution Urban Transport Systems," paper presented at the 2nd KFB-Research Conference, Lund.

Boerkamps, J. H. K., Binsbergen, van A. J., and Bovy, P. H. L. (2000), "Modeling Behavioral Aspects of Urban Freight Movement in Supply Chains," *Transportation Research Record*, 1725: 17-25.

Bon, R. (1984), "Comparative Stability Analysis of Multiregional Input-Output Models: Column, Row and Leontief-Strout Gravity Coefficient Models," *Quarterly Journal of Economics*, 99: 791-815.

BTS. (2010), "Freight Transportation: Global Highlights - U.S Trends 2010." [On-line]. Available: http://www.bts.gov/publications/freight_ transportation /html/us_trends.html. Accessed: 9/16/10.

Cascetta, E. (2001), "National Modeling in Italy; Simulation and Evaluation Models For The Italian DSS," paper presented at Seminar on National Transport Models: The State of the Art, Noordwijk.

Chenery, H. (1953), "The Structure and Growth of the Italian Economy," *Regional Analysis*, 97-116.

Corbett, C. J. and Klassen, R. D. (2006), "Extending the Horizons: Environmental Excellence as Key to Improving Operations," *Manufacturing and Service Operations Management*, 8(1): 5-22.

Daugherty, P. J., Autry, C. W. and Ellinger, A. E. (2001), "Reverse Logistics: The Relationship Between Resource Commitment And Program Performance," *Journal of Business Logistics*, 2: 107–123.

Dougherty, M. (1995), "A Review of Neural Networks Applied To Transport," *Transportation Research Part C*, 3(4): 247–260.

Fischer, M., Outwater, M.L., Luke Cheng, L. D., Ahanotu, N. and Calix, R. (2005), "An Innovative Framework for Modeling Freight Transportation in Los Angeles County," *Transportation Research Record No. 1906:* 105-112.

Friedrich, H, and Liedtke, G. (2009), "Consideration of Logistics for Policy Analysis with Freight Transport Models," Institute for Economic Policy Research, University Karlsruhe, Karlsruhe, Germany.

Hamburg, J. (1958), "Computer Models of Traffic Patterns in the Detroit Region," Detroit Transport Memorandum 17.

Hertz, S., and Alfredsson, M. (2003), "Strategic Development of Third Party Logistics Providers," *Industrial Marketing Management*, Vol. 32 (2): 139–149.

Holguin-Veras, J., and Thorson, E. (2003), "Modeling Commercial Vehicle Empty Trips With A First Order Trip Chain Model," *Transportation Research Part B*, 37 (2): 129-148.

Holmblad, M. (2004), "Modeling of Freight Transport Logistics in a Meso-Economic Framework," Danish Transport Research Institute.

Jin, Y., Williams, I., and Shahkarami, M. (2005), "Integrated Regional Economic And Freight Logistics Modeling: Results From A Model For Trans-Pennine Corridor," paper presented at the 2005 European Transport Conference Strasbourg, Association for European Transport, London.

Jong, de, G., Ben-Akiva, M., Florian, M., Gronland, S.E., and Van Der Voort, M. (2005), "Specification of a Logistics Model for Norway and Sweden," paper presented at the 2005 European Transport Conference Strasbourg, Association for European Transport, London.

Leontief, W. (1936), "Quantitative Input and Output Relations in the Economic System of The United States," *The review of Economics and Statistics*, 18: 105-125.

Lieckens, K., and Vandaele, N. (2007), "Reverse Logistics Network Design: The Extension Towards Uncertainty," *Computers and Operations Research*, 34(2): 395 – 416.

Mollenkopf, D., Stolze, H., Tate, W., and Ueltschy, M. (2010), "Green, Lean, and Global Supply Chains," *International Journal of Physical Distribution and Logistics Management*, 40 (1/2): 14 – 41.

Moses, L.N (1955), "The Stability of Interregional Trading Patterns and Input-Output Analysis," *American Economic Review*, 45: 803-832.

Oum, T. (1989), "Alternative Demand Models And Their Elasticity Estimates," *Journal of Transport Economics and Policy*, 23: 163-187.

RAND Europe, Oxford Systematics and Parson Brinckerhoff. (2002), *Review of Freight Modeling, Report on Task B2: Models in Continental Europe and Elsewhere*, Report for the U.K. Department of Transport, Cambridge.

Samimi, A., Mohammadian, K. and Kawamura, A. (2009), "Behavioral Freight Movement Modeling," paper presented at the 12th International Conference on Travel Behavior Research, Jaipur, India.

So, S-H., Kim, J-J., Cheong, K-J., and Cho, G. (2007), "Evaluating The Service Quality Of Third Party Logistics Service Providers Using The Analytic Hierarchy Process," *Journal of Information Systems and Technology Management*, 3(3): 261-270.

Tavasszy, L. A. (2006), "Freight Modeling – An Overview of International Experiences," paper prepared for the TRB Conference on Freight Demand Modeling: Tools for Public Sector Decision Making, Washington DC.

Tavasszy, L.A., Smeenk, B., and Ruijgrok, C.J. (1998), "A DSS for Modeling Logistic Chains in Freight Transport Policy Analysis," *International Transactions in Operational Research*, 5: 447-459.

Tian, Y., Ellinger, A.E. and Chen, H. (2010), "Third-Party Logistics Provider Customer Orientation and Customer Firm Logistics Improvement in China," *International Journal of Physical Distribution & Logistics Management*, 40(5): 356-376.

Williams, I., and Raha, N. (2002), "Review of Freight Modeling," Final Report, DfT Integrated Transport and Economic Appraisal, Cambridge, UK.

Winston, C. (1983), “The Demand for Freight Transportation: Models And Applications, *Transportation Research Part A*, 17(6): 419-427.

Yang, H. C., Regan, C. A. and Son, T. Y. (2009), “Another View of Freight Forecasting Modeling Trends,” *KSCE Journal of Civil Engineering*, 14(2): 237-242.

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