Abridgment

Short-Run Freight-Demand Model: Joint Choice of Mode and Shipment Size

Y.S. CHIANG, PAUL O. ROBERTS, JR., AND M. BEN-AKIVA

An important part of any quantitative analysis of freight transportation is a capability for forecasting the demand for a certain type of service under a given set of conditions. Unfortunately, the state of the art in freight-demand modeling is still rather primitive. It is clear that the firm is the basic decision-making unit in the transportation of freight. However, the role of the firm in selecting freight transportation service has not been explored satisfactorily. Most of the existing freight-demand models are correlative rather than explanatory and insensitive to changes in transport level-of-service measures. Researchers in the past have been constrained either to piecing together useful aggregate data to estimate an aggregate demand model or to using shipper surveys to estimate a very limited shipper-choice model. An attempt to develop a freight-demand model that involves the choice of mode as well as shipment size without imposing the assumption of constant transportation rate is given. A multinomial logit model of mode and shipment size is developed at the level of the individual firm. The utility function is derived from logistics inventory theory that considers explicitly the trade-offs the firm can make in response to a short-run change in transportation level of service. The major assumption is that the substitution between transportation and other factors of production, such as labor and capital, is relatively inelastic when compared with the substitutions that can take place within the transportation sector itself.

An important part of any quantitative analysis of freight transport is a capability for forecasting the demand for a certain type of service under a given set of conditions. Unfortunately, the state of the art in freight-demand modeling is still rather primitive. It is clear that the firm is the basic decision-making unit in the transportation of freight. However, the role of the firm in selecting freight transportation service has not been explored satisfactorily. Most of the existing freight-demand models are correlative rather than explanatory and insensitive to changes in transportation level-of-service measures. This is primarily due to two factors. The first is the data limitations. Data that can be used to undertake a careful estimation of a disaggregate behavioral freight-demand model are almost nonexistent. Thus, researchers in the past have been constrained either to piecing together useful aggregate data to estimate an aggregate demand model (1-3) or to using inadequate shipper surveys to estimate a very limited shipper-choice model (4,5).

A second limitation comes from the fundamental difficulties that most researchers have experienced in attempting to apply economic theories of derived demand to freight-demand analysis without making unattractive simplifying assumptions. One frequently used assumption is constant transport cost. That is, the freight rate is assumed not to be influenced by the quantity shipped. This makes the model policy insensitive to changes in the transportation level of service (6).

This paper represents an attempt to develop a freight-demand model that involves the choice of mode as well as shipment size without imposing the assumption of constant transport rate. A multinomial logit model of mode and shipment size is developed at the level of the individual firm. The utility function is derived from logistics inventory theory, which considers explicitly the trade-offs the firm can make in response to a short-run change in transportation level of service. The major assumption is that the substitution between transportation and other factors of production, such as labor and capital, is relatively inelastic when compared with the substitutions that can take place within the transportation sector itself.

MODEL FORMULATION

A short-run logistics choice involves the choice of mode (m), shipment size (q), and point of supply (i) given the annual use rate of inputs by the firm (x). The annual use rate, or the level of input, is treated as given. The firm exercises logistics strategies to minimize its purchase and logistics costs for these inputs. Thus, the variables i, m, and q define the possible alternative logistics strategies open to a firm. An optimal strategy is said to be one that has the lowest total purchase and logistics costs. Mathematically, that is as follows:

$$w = \min_{i,m,q} w_{imq} [P_{iq}(x) + T_{imq}(x)] \tag{1}$$

where w is annual total cost for an input commodity, P is purchase costs, and T is logistics costs.

There appear to be two general approaches one can take in modeling the logistics decision of a firm. The difference between the two approaches lies in the assumption involved in the level of certainty concerning the information in the logistics cost function given in Equation 1. In the first approach, the logistics cost function is assumed to be fully observable. Therefore, the alternative defined by the choice of i, m, q is selected with certainty if $w_{imq} < w_{i'm'q'}$, $\forall_{i'm'q'} \epsilon A$, where A is the choice set. A model developed on this assumption can be referred to as a deterministic cost model of short-run freight demand (7).

The second approach assumes that the logistics cost function is not fully observable. Only part of the cost function is observed. Denoting $w_{imq}{}^{o}$ as the observable part of the logistics cost function and $w_{imq}{}^{u}$ as the unobservable part of the logistics cost function, we have $w_{imq} = w_{imq}{}^{o} + w_{imq'}{}^{u}$ $\forall_{imq} \epsilon A$. The unobservable part is assumed to be a random variable. Thus, probabilistic models can be derived by assuming appropriate distributions for the unobserved random variables. For example, assuming that they are independently and identically Gumbel distributed, the following multinomial logit model results:

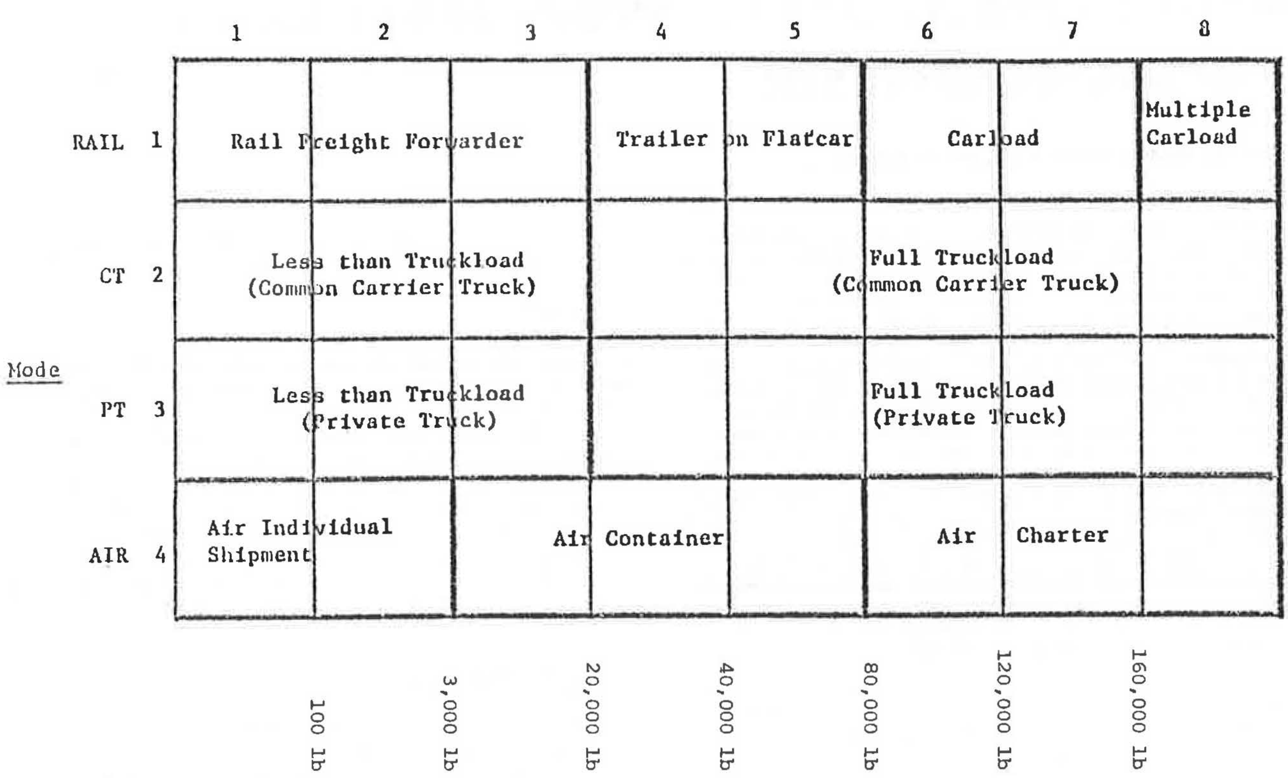
$$P_r(imq|A) = \exp(-\mu w^{o}_{imq}) / \sum_{i'm'q' \epsilon A} \exp(-\mu w^{o}_{i'm'q'}) \tag{2}$$

where μ is the scale factor of a logit model. Models of this type can be referred to as random-cost models of short-run freight demand.

DEVELOPMENT OF DISAGGREGATE DATA BASE

To implement the model described here we used the 1972 Census of Transportation Commodity Transportation Survey (CTS) as the basic data base. We considered four modes and eight shipment-size categories. A mode and shipment-size combination represents an alternative transport service. The definition of choice alternatives is shown in Figure 1.

Figure 1. Definition of choice alternatives.



The data base was prepared by using the following procedures: (a) the records in the census are skimmed for records that are complete at the five-digit Standard Transportation Commodity Code (STCC) level; records for rail, common carrier truck, private truck, or air are chosen; (b) these records are extracted and expanded to produce the basic disaggregate data set; (c) a representative annual use rate is sampled for each shipment by using the procedures developed by Chiang and Roberts (8); (d) the unchosen alternatives that are to be considered for each shipment are chosen; and (e) transportation level-of-service attributes are developed for both chosen and unchosen alternatives.

The transportation level-of-service variables required in the model specification include freight rate and special charges, mean transit time, waiting time, transit-time reliability, loss and damage, and the time required to complete the investigation of loss and damage claims. We used a set of level-of-service models developed by the Massachusetts Institute of Technology (MIT) Freight Research Group, which have been documented by Roberts and Wang (9) and by Chiang and Roberts (10). The commodity attributes are taken from the commodity attribute file assembled at MIT from data obtained from a number of sources and documented by Kuttner (11).

SPECIFICATION OF LOGISTICS COST FUNCTION FOR JOINT-CHOICE MODEL OF MODE AND SHIPMENT SIZE

From inventory theory, the logistics cost faced by a receiver can be expressed as the sum of the order cost, transportation cost, capital carrying cost in transit, capital carrying cost in storage, stockout cost, etc., associated with a given logistics strategy. Assuming that there is no quantity discount in purchase, these cost components are the costs (disutilities) to be minimized in a joint choice model of mode and shipment size. The specification of these cost components as well as other variables are discussed as follows.

Transportation Charges

Transportation charges can be specified simply as $\beta_1(\text{RATE}_{imq} + \text{SPC}_{imq}) \cdot x$, where RATE is the freight rate, SPC is any special charges associated with the shipment such as pickup and delivery charges for trailer-on-flatcar service, and x is the annual use rate. The coefficient β_1 serves as a scaling factor.

Capital Carrying Cost in Storage

The average inventory level for nonsafety stock is assumed to be one-half of the shipment size. On the average, this amount of stock is held in storage for the time between orders. In practice, additional safety stock is held to protect against stockout (9). The amount of safety stock is assumed to be the reliability of transportation service in days multiplied by daily use rate of the commodity. Thus, capital carrying cost tied up in storage can be specified as $\beta_2 \cdot [(q/2) + R_{imq} \cdot u] \cdot P_1$, where reliability R is measured as transit time beyond the mean at a level of confidence of 90 percent, u is the daily use rate, q is the shipment size, and P is the purchase price of the commodity. Dividing β_2 by β_1 will produce an estimate of the implied interest rate.

Capital Carrying Cost in Transit

We specify two cost components--capital carrying cost during transit time and capital carrying cost from the time of arrival until a loss-and-damage claim is settled if loss and damage did occur. The specification is as follows:

$$\beta_n \cdot [(TT_{imq}/365) + (LDP_{imq} \cdot IT_m)/365] \cdot P_i \cdot x \quad (3)$$

where TT is mean transit time in days and LDP is the percentage of goods lost and damaged. IT is the time required to finish the investigation of a loss-and-damage claim and to pay the claim.

We have specified capital carrying cost in transit as two variables--one for emergency shipments (n = 3) and the other for regular shipments (n = 4). We define a shipment to be an emergency shipment if the annual use rate divided by the chosen shipment size is greater than 52; i.e., more than one order per week would be required if this shipment size were chosen regularly. Dividing $\beta_3(\beta_4)$ by β_1 will produce an estimate of the implied interest rate for these two types of shipments.

Order Cost

Order cost can be specified as $\beta_5 (P_i \cdot q)^{0.4} \cdot (x/q)$. This specification allows order cost to vary with the amount of a purchase, considering the fact that one is usually willing to spend more to process an order for a large purchase than for a small one.

Loss of Value During Transit or Storage

The loss of shelf life during transit or storage is important for time-sensitive goods such as newspapers and for perishable goods such as fruits and vegetables. We have specified this cost item as $\beta_6 \cdot [q - u(SHELF - TT_{imq} - WT_{imq})] \cdot P_i \cdot (1/q) \cdot x$, where SHELF is shelf life in days. The term $(SHELF - TT_{imq} - WT_{imq})$ is the time available to use the time-sensitive or perishable goods. Thus, $u \cdot (SHELF - TT_{imq} - WT_{imq})$ is the maximum shipment size for these goods if there is to be no loss due to spoilage or time loss of utility. The complete expression $\beta_6 \cdot [q - u \cdot (SHELF - TT_{imq} - WT_{imq})] \cdot P_i \cdot (1/q) \cdot x$ reports the loss of value associated with the shipment size q. The terms $(SHELF - TT_{imq} - WT_{imq})$ and $[q - u \cdot (SHELF - TT_{imq} - WT_{imq})]$ are restricted to be nonnegative.

Mode and Shipment Size Constants

Mode and shipment-size constants (β_7 to β_{22}) are specified to measure "pure-alternative" effects, i.e., the net effect of all attributes of an alternative not measured by other variables. The definitions of all variables are summarized in Table 1. All cost variables are specified as generic variables.

ESTIMATION RESULTS

The estimated results of the joint-choice model of mode and shipment size were performed by using maximum-likelihood procedures. By using the likelihood-ratio test, the hypothesis that all parameters are zero is significantly rejected.

The magnitudes of the coefficients should be interpreted relatively because the coefficients of the logit model are estimated as multipliers of the scale parameter μ. In order to draw economic inferences, we thus normalize the coefficients of all cost variables by the coefficient of TCOST. The results are shown below:

Variable	Normalized Coefficient
TCOST	1.0
CCCIS	0.571
CCCIT1 (emergency shipments)	45.783
CCCIT2 (regular shipments)	1.239
ODC	1.387
LOSSV	0.492

The normalized coefficient of CCCIS (0.571) gives the revealed preference on interest rate per year implied by the shipper's observed decisions. Note that the results are estimated to be significantly higher than the normal market cost of capital. The interest rate for capital carrying cost in transit for regular shipments is especially high (1.239), which indicates that shippers in the real world may have overemphasized the importance of transit time. This translates into a transit-time value of $0.003/day per dollar of value. This might also be explained by the uncertainty of transit time and the associated consequences of stocking out. The coefficient of CCCIT1 is estimated much higher than that of CCCIT2, which follows our expectations. Its normalized coefficient value of 45.783 translates into a transit time value of $0.125/day per dollar of value. For emergency shipments, travel time is obviously a major factor in the determination of modal choice.

Table 1. Definitions of variables for joint-choice model of mode and shipment size.

Parameter	Variable	Definition
β_1	TCOST	Transport rate and special charges
β_2	CCCIS	Capital carrying cost in storage
β_3	CCCIT1	Capital carrying cost in transit or tied up with a loss-and-damage claim for emergency shipment
β_4	CCCIT2	Capital carrying cost in transit or tied up with a loss-and-damage claim for regular shipment
β_5	ODC	Order cost
β_6	LOSSV	Loss of value during transit or storage
β_7 to β_{22}		Alternative dummy variables

SUMMARY AND CONCLUSIONS

This paper has shown only a very small part of what is rapidly becoming a powerful set of techniques for developing freight-flow information. This information could be of immense use to managers and policymakers for use in logistics planning, marketing, capital budgeting, and investment decisions. A disaggregate freight-demand model such as the one described here obviously occupies a key role among the available techniques, since it not only offers a way to resolve the modal-choice questions but it also begins to explain the underlying shipper behavior. Operational models such as this one are, however, only a first step, albeit an extremely important one, to successful application to real-world problems.

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Abridgment

Potential Demand for Passenger Rail Intercity Traffic and Possibility of Increasing Demand

WERNER BRÖG, WOLFGANG BLECHINGER, AND KLAUS HUBER

In the spring 1979, the Deutsche Bundesbahn (DB) (German Railroad Association) introduced a new system—Intercity (IC) 1979. Due to its innovations (average travel-time reduction by 20 percent, two-class train system, increased number of trains on a firm hourly schedule, and improved comfort), DB hoped to increase its number of potential passengers by inducing those who had previously used automobiles and airplanes to use the IC 1979 trains. The survey described here confirmed that this new concept would be successful. This was shown not only in the users' positive evaluations of the new system but also in the increased amount of travel (about 15 percent) on IC trains during the survey. Almost all the new passengers travel second class because of the deliberate change from exclusive IC trains to a fast, comfortable transportation mode for a broader spectrum of the population. An analysis of the potential increase in the number of passengers has proved the effectiveness of the new IC 1979 system.

Analysis of the entire market for intercity travel in the Federal Republic of Germany and the trend of the market in passenger rail travel in special segments of this market has shown basic changes in market potential and market structure in recent years. The percentage of trips for which individual transportation modes are used has consistently increased; it is now about 80 percent. In contrast to this, in 1975, for instance, passenger rail traffic accounted for only about 9 percent of the intercity traffic volume. In order to compete with cars and airplanes, it was of utmost importance for the Deutsche Bundesbahn (DB) (German Railroad Association) to improve the speed with which their trains traveled. The DB's market position could only be improved by catering to the most important customer demands. Thus, a thorough analysis of the total intercity passenger market and the development in demand for passenger rail traffic in the different market areas and intensive market research studies were performed prior to the institution of a new (two-class) train system.

The goal of the research was to show all the ways in which an improved offer could be adapted to market requirements and to extend the improvements to as much as possible. This meant that one needed to identify the criteria that determined choice of mode of transportation, to analyze these criteria, and then to classify them according to order of importance. The investigation identified the following factors as important for keeping current railroad patrons and substantially increasing the number of future railroad customers:

1. Travel time must be reduced,
2. Number of direct connections must be increased,
3. Trains must travel more frequently, and
4. Traveling must be made more comfortable.

For this purpose, DB introduced new and improved intercity (IC) 1979 trains on May 27, 1979, after a preliminary one-year test of this offer on the route from Hamburg to Cologne. Important characteristics of the new IC trains for passengers were introduction of the two-class system for all IC trains, increasing the speed of IC trains by 26 percent or 20 km/h as compared with that of the D-Züge trains, and a consistent hourly schedule. The results of these and other measures were to be studied in a market survey (1).

Four kinds of trains for intercity travel are mentioned repeatedly in this paper. These are the trans-European express (TEE) trains, which travel between the major cities of Europe, make relatively few stops, and only have first-class cars; IC trains, which are similar to TEE trains but travel only within Germany; and the new IC 1979 trains mentioned in this paper, which now have two classes--the D-Züge, a two-class express train that travels within Germany and is slower than the TEE and IC trains and makes more stops, and the Eilzüge, which has two classes and is used for short trips.

RESEARCH CONCEPT

In order to deal successfully with the primary goal