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Publication of this paper sponsored by Committee on Freight Transportation Planning and Marketing.

Factors That Determine Mode Choice in the Transportation of General Freight

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ABSTRACT

This study examines the factors that influence the mode choice decisions of shippers of general freight commodities in the Atlantic provinces of Canada. The study employed a mail-response questionnaire directed to randomly selected manufacturers to determine the basis of each firm's decision to ship by its regular mode. Respondents were required to identify the product shipped most frequently by the firm and the most regular origin-destination link. They were then required to provide pertinent details, such as transit time, shipping costs, and frequency of shipments, relating to the shipment of that product on the identified origin-destination link. Linear logit models were used to determine the variables that influence the selection of various modes for goods shipments and the relationship between the utility of each mode and the explanatory variables. The models obtained were as intuitively expected. It is concluded that logit analysis using survey data represents a valid and potentially more useful methodology than the use of waybill data. It is recommended that further research using the suggested model forms and data obtained from personal interviews of shippers would improve the quality of the results and provide a greater understanding of the shipper mode choice decision process.

Freight transport carriers in Canada face two serious challenges. One is the slowdown in growth of the freight transport market over the next two decades, as predicted in a paper published by Transport Canada (1, p.i). It is stated in the paper, however, that during the 1980s this growth rate is expected to drop to about 3 percent annually. The reasons given for this lower rate of growth include "a slower pace of economic growth, higher energy costs, higher labor income relative to productivity increases, and relatively fewer technological gains, which could otherwise reduce prices and lower costs."

The other challenge is deregulation of the freight transport market. These challenges will take the form of increasing competition for a slow-growing market. The major problem facing carriers, therefore, under the twin threats of economic and regulatory instability, is the determination of the combinations of service and price that specified categories of shippers would find acceptable for the shipment of their goods.

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The objectives of this research are

1. To determine the factors that affect the mode choice decisions of shippers of general freight commodities and the relationship between the service attributes offered by a mode and the utility of that mode to shippers and
2. To determine if survey rather than waybill data can be used to study the mode choice decisions of shippers of general freight commodities.

DATA

Previous studies of modal choice in freight transportation have used the data recorded on freight waybills or the same data compiled in data banks. The advantage of using this type of data is that much of the information, such as freight rate and transit time, is precisely recorded and the explanatory variables, therefore, do not have appreciable measurement errors. Unfortunately, however, there are a number of problems with waybill data, some of which are

1. Waybills usually record only a few system variables and supply no information about the level of service attributes and the way shippers view those service attributes. The data are therefore unsuitable for a behavioral analysis of all the probable factors affecting mode choice.
2. Many of the data items recorded on waybills are difficult to integrate and use because of differences in recordkeeping among the various modes with respect to commodity classification, units of measurement, and so forth.
3. Shippers generally consider the information on their waybills sensitive and tend to refuse to release their waybills for research purposes.

The alternative to using waybill data is to carry out a survey of shippers. There are two main problems with this method. First, the survey procedure itself is subject to a number of errors. The errors that generally occur in surveys are discussed in detail by Deming (2). Sources of error in surveys conducted in the area of behavioral travel research are treated by Wermuth et al. (3). Second, it is argued that the variables obtained in a survey are imprecise because there are sometimes differences between the actual values of the variables and the values perceived by shippers.

The advantage of surveys is that it is possible to obtain the views of the shippers about as many choice-influencing variables as are considered appropriate for the study in question. The errors inherent in the survey procedure can be minimized by careful attention to the questionnaire design and sampling techniques. Even the difference between perceived and actual values of the variables on the part of shippers need not be a disadvantage. It is argued that because shippers base their decisions on their perceptions of the attributes of the various modes, the perceived variables are the correct ones to use.

For these reasons, it was decided to use a survey to obtain information on individual shipments from a sample large enough to be representative of the shipping population in the Atlantic provinces. A mail-response survey was selected over personal and telephone interviews as the most realistic means of collecting data for this research given the financial, time, and accuracy constraints. The survey was conducted in September 1984. A sample of randomly selected manufacturing industries based in the Atlantic provinces was surveyed to determine the basis of each shipper's decision to use its preferred mode for goods shipments. Respondents were required to identify their main product and their most important origin-destination (O-D) link and then to answer a number of questions about the shipment of that commodity on the listed O-D link. The main product was defined in this research as the product that the company ships most frequently. The breakdown of returns into mode choices is as follows:

Mode	Number	Percentage
Hired trucks	66	51.56
Private trucks	41	32.03
Rail	10	7.81
Mail	6	4.69
Air	4	3.12
Ship	1	0.78

ANALYSIS

The factors that influence the mode choice decisions of shippers may be roughly classified into four groups: characteristics of the transportation system, characteristics of the shipment, characteristics of the local carriers, and characteristics of the shipper. The variables introduced into some or all of the models calibrated are given in the following subsections.

Characteristics of the Transportation System

C = shipping cost per pound of the commodity on the defined O-D link;
T = transit time in days from departure at origin to arrival at destination;
D = in-transit damage or loss in cents per pound of commodity shipped; and
R = reliability of transit time delivery, defined as the percentage of time that shipments are judged to have arrived at the destination early or on time.

Characteristics of the Shipment

F = frequency of shipment of commodity on specified O-D link,
V = market value per pound of the commodity, and
S = shipment size in pounds.

Characteristics of the Carriers

A = 1 if the shipment tracing capability of the carrier is considered important in the choice of the mode and
  = 0 otherwise,
P = 1 if cooperation between shipper and carrier personnel is considered important in the choice of the mode and
  = 0 otherwise,
G = 1 if the geographic coverage offered by the carrier is considered important in the choice of the mode and
  = 0 otherwise, and
K = 1 if pickup services are provided by the carrier and
  = 0 otherwise.

Characteristics of the Shipper

W = 1 if the shipper has reviewed the mode of transportation of the commodity within the past 12 months and
  = 0 otherwise, and
E = experience of the shipper in years.

Derived Variables

C_m = shipping cost/commodity value derived from the hypothesis that the degree of importance of shipping cost to a shipper has an inverse relationship with the value of the commodity;
T_m = frequency of shipment times transit time, derived from the hypothesis that the perception of the importance of transit time is related to the frequency of shipment; and
R_m = frequency of shipment times reliability, derived from the hypothesis that the perception of the importance of reliability of transit time delivery is directly related to the frequency of shipment of the commodity.

Models

The analysis was performed using linear logit models of the form

$$P_m = \exp U_m / \Sigma_N \exp U_n \qquad n = 1, \ldots, N \tag{1}$$

where

P_m = probability of choice of mode m,
U_m = utility of mode m, and
N = number of modes.

Therefore,

$$P_H = \exp U_H / (\exp U_H + \exp U_P + \exp U_R) \tag{2}$$

$$= 1/[1 + \exp(U_P - U_H) + \exp(U_R - U_H)] \tag{3}$$

Similarly,

$$P_P = 1/[1 + \exp(U_H - U_P) + \exp(U_R - U_P)] \tag{4}$$

and

$$P_R = 1/[1 + \exp(U_P - U_H) + \exp(U_R - U_H)] \tag{5}$$

U_H, U_P, and U_R are utility functions determined using maximum likelihood estimation procedures and are expressed as

$$U_m = \alpha_0 + \sum_{j=1}^{n} \alpha_j X_j \tag{6}$$

where

α_0, α_j = parameters determined by maximum likelihood estimation procedures and
X_j = explanatory variables.

It was noted that in-transit damage and commodity value are highly correlated and may not be used in the same model because of multicollinearity problems. Two alternative forms of a model that contains the direct explanatory variables are therefore tested; the only difference between the two models is the alternative specifications of in-transit damage and commodity value. A third model is specified using the derived variables instead of the corresponding direct variables. The three model specifications are as follows:

Model 1a

$$U_m = \alpha_0 + \alpha_1 C + \alpha_2 T + \alpha_3 D + \alpha_4 R + \alpha_5 S + \alpha_{16} F + \alpha_6 E + \alpha_7 A + \alpha_8 G + \alpha_9 P + \alpha_{10} K + \alpha_{11} W \tag{7}$$

Model 1b

$$U_m = \alpha_0 + \alpha_1 C + \alpha_2 T + \alpha_{12} V + \alpha_4 R + \alpha_5 S + \alpha_{16} F + \alpha_6 E + \alpha_7 A + \alpha_8 G + \alpha_9 P + \alpha_{10} K + \alpha_{11} W \tag{8}$$

Model 2

$$U_m = \alpha_0 + \alpha_{13} C_m + \alpha_{14} T_m + \alpha_{15} R_m + \alpha_3 D + \alpha_5 S + \alpha_6 E + \alpha_7 A + \alpha_8 G + \alpha_9 P + \alpha_{10} K + \alpha_{11} W \tag{9}$$

Three sets of computations of P_M are made; in each set the three alternative specifications of U_M are used. The statistical properties of each set of computations and comparisons of the signs of parameter coefficients with expected shipper behavior are used to determine which factors best explain the choice of each mode.

RESULTS

The results of the model calibrations are presented in this section. For each model specification, the variables found to be significant in influencing the choice of that mode and associated statistics are presented. In all cases, the two alternative specifications of Model 1 produced identical results because neither in-transit damage in Model 1a nor commodity value in Model 1b was found to be significant.

Hired Truck

The variables that are significant for the choice of hired truck and model statistics are given in Tables 1 and 2. The results of the model calibrations for the hired truck mode are

1. For Model 1, the signs of the parameters for those variables significant in explaining the choice of the hired truck mode are as expected. The parameter estimates for transit time and frequency have negative values, confirming that the utility of the mode decreases with increasing transit time and with increasing frequency of shipment. Similarly, the positive signs for the parameter estimates of pickup and cooperation indicate as expected that the utility of the hired truck mode increases with greater cooperation between shipper and carrier personnel and

TABLE 1 Variables That Are Significant for Choice of Hired Truck

Variable	Parameter	Estimate	Standard Error	t-Value	R-Value
Model 1					
Intercept	α_0	0.115	0.277	0.17	
Frequency	α_{16}	-1.006	0.469	4.61	-0.121
Transit time	α_2	-1.142	0.338	11.41	-0.231
Cooperation	α_9	0.682	0.303	5.08	0.132
Pickup	α_{10}	1.845	0.334	30.59	0.402
Model 2					
Intercept	α_0	0.379	0.300	1.59	
Frequency x time	α_{14}	-1.271	0.355	12.82	-0.247
Tracing	α_7	-0.594	0.320	3.44	-0.090
Cooperation	α_9	1.029	0.353	8.51	0.192
Pickup	α_{10}	1.911	0.343	30.96	0.405

TABLE 2 Model Statistics for Hired Truck

Model	-2 Log L	Degrees of Freedom	P	R-Value	Signs
1	89.53	4	0.000	0.670	All signs correct
2	85.31	4	0.000	0.687	One sign incorrect

also when pickup services are provided by the carrier.

2. For Model 2, the signs of the parameters of most significant variables are as expected, except for the parameter for the variable tracing. The negative sign for the parameter appears to indicate that the greater the shipment-tracing capability of the carriers, the lower the utility of the mode to shippers. This is contrary to expected shipper behavior.

3. The P-values indicate that the hypothesis of independence between the probability of choice of the hired truck mode and the explanatory variables of the model may be safely rejected. The t-values and partial R-values are higher for most of the variables in Model 2 than for the corresponding values for Model 1, which indicates that the parameter estimates for Model 2 are slightly better.

4. The R-value for Model 2 is slightly higher than the corresponding value for Model 1, but statistically there is not much difference in goodness-of-fit between Model 1 and Model 2.

All the statistics associated with the variables and with the two models indicate that Model 2 is slightly better than Model 1 at explaining the factors that influence the choice of the hired truck mode. However, the dominant feature in the validity of the two models is the incorrect sign of the parameter for the tracing variable in Model 2, which leads to conclusions that are contrary to expected shipper behavior. Therefore, better statistics notwithstanding, Model 2 is on the whole less satisfactory than Model 1 in explaining the factors that influence the choice of the hired truck mode and is rejected. The model that explains the variables that influence the choice of the hired truck mode is, therefore, given by

$$U_H = 0.277 - 1.006\ F - 1.142\ T + 0.682\ P = + 1.845\ K$$

Private Truck

The variables that are significant for the choice of private truck and model statistics are given in Tables 3 and 4. The results of the model calibrations for the private truck mode are

1. For both Model 1 and Model 2 the signs of the parameters of the variables that influence the choice of private truck are as intuitively expected. The negative sign for transit time indicates that the attractiveness of the private truck mode decreases with increasing transit time, and the positive sign for frequency indicates that the utility of the mode increases with increasing frequency of shipment. The signs of the parameters for derived transit time and derived reliability are also as expected.

2. The P-values indicate that the hypothesis of independence between the choice of private truck and the explanatory variables of the model can be safely rejected.

TABLE 3 Variables That Are Significant for Choice of Private Truck

Variable	Parameter	Estimate	Standard Error	t-Value	R-Value
Model 1					
Intercept	α_0	-1.032	0.255	16.32	
Frequency	α_{16}	0.642	0.318	4.09	0.114
Transit time	α_2	-1.219	0.426	8.20	-0.196
Model 2					
Intercept	α_0	-0.839	0.221	14.43	
Frequency x time	α_{14}	-0.973	0.395	6.08	-0.159
Frequency x rely	α_{15}	1.253	0.391	10.25	0.227

TABLE 4 Model Statistics for Private Truck

Model	-2 Log L	Degrees of Freedom	P	R-Value	Signs
1	137.43	2	0.000	0.345	All signs correct
2	141.31	2	0.001	0.308	All signs correct

Statistically, Model 1 performed slightly better than Model 2 in explaining the variables that influence the choice of private truck as the preferred freight transport mode. However, on an intuitive level, it may be noted that Model 2 demonstrates the influence of one additional variable the effect of which is not shown by Model 1: reliability of transit time. For the purposes of this research, therefore, Model 2 has a greater explanatory power than does Model 1 and is selected as the model better capable of indicating the factors that influence the choice of the private truck mode. Model 2 is presented as

$$U_P = -0.839 - 0.973\ T_m + 1.253\ R_m$$

Rail

The variables that are significant for the choice of rail and model statistics are given in Tables 5 and 6. The results of the model calibrations for the rail mode are

1. It is observed from Model 1 that the signs of all of the parameters of the variables that influence the choice of the rail mode are as intuitively expected. The parameters for the variables pickup and

TABLE 5 Variables That Are Significant for Choice of Rail

Variable	Parameter	Estimate	Standard Error	t-Value	R-Value
Model 1					
Intercept	α_0	-3.602	0.708	25.87	
Time	α_2	1.038	0.330	9.91	0.336
Tracing	α_7	0.590	0.334	3.13	0.127
Pickup	α_{10}	1.036	0.588	3.11	0.126
Model 2					
Intercept	α_0	-3.120	0.507	37.92	
Frequency x time	α_{14}	0.811	0.258	9.91	0.336
Tracing	α_7	0.894	0.340	6.92	0.265

TABLE 6 Model Statistics for Rail

Model	-2 Log L	Degrees of Freedom	P	R-Value	Signs
1	49.48	3	0.001	0.458	All signs correct
2	54.11	2	0.003	0.415	All signs correct

tracing are both positive, which indicates that these variables have a positive effect on the probability of choice of the rail mode. The positive parameter for transit time implies that as shipping distances (for which transit time is serving as a proxy) increase, the attractiveness of the rail mode increases. This result is consistent with the observed shipper behavior. Similarly, the signs of the parameters of derived transit time and shipment tracing capability in Model 2 are consistent with expected shipper behavior.

2. The P-values indicate that the hypothesis of independence between the probability of choice of the rail mode and the values of the explanatory variables in the models may be safely rejected.

The statistics associated with Model 1 and Model 2 indicate that the two models have approximately equal power to explain the factors that influence the choice of the rail mode. However, Model 1 has one more degree of freedom than does Model 2 and is considered the better model. The model that best explains the factors that affect the choice of the rail mode, therefore is

$$U_R = -3.602 + 1.038\ T + 0.590\ A + 1.036\ K$$

Discussion of Results

The results from the research show that the variables that influence the choice of the hired truck mode are frequency of shipment, transit time, provision of pickup services, and cooperation between shippers' and carriers' personnel. The partial R-values for the variables indicate that the single most important factor, which accounts for almost half of the explanatory power of the model, is the provision of pickup services. The other significant variables in order of decreasing importance are transit time, cooperation, and frequency.

The factors that influence the decision to use private truck are the derived variables for transit time and reliability of transit time. The t-values of the significant variables indicate that the intercept term makes the highest contribution to the explanatory power of the model, followed in order by derived reliability and derived transit time.

It is pertinent in this context to discuss the significance of the intercept term. The intercept term accounts for other nonquantifiable variables (such as personal biases and prestige value) that affect the mode choice decision but that are not included in the model. Hence the intercept term approaches zero as more of the significant factors are included in the model and reduces to zero when all factors that affect the mode choice decision are accounted for in the model. That the intercept term in the private truck model makes the highest contribution to the explanatory power of the model implies that the most important factors influencing the decision to use private truck have not been identified in this research and may, indeed, not be quantifiable. Of the quantifiable factors, the importance of the derived variables for reliability and transit time in the mode choice decision are exactly as intuitively expected.

The important factors that influence the choice of the rail mode are transit time, shipment tracing capability of the carriers, and provision of pickup services. The t-values indicate that the highest contribution to the explanatory power of the model defining the utility of the rail mode is provided by the intercept term, followed in order by transit time, shipment tracing capability, and provision of pickup services. Again, the implication here is that factors other than those included in the model heavily influence the decision to use rail. The signs of the parameters of all of the significant variables are as intuitively expected.

In most cases statistics associated with the two model forms tested were within the same value ranges. On an intuitive level, Model 1 is the better specification because it shows the correct signs on all parameters of significant variables for all modes whereas Model 2 produces an incorrect sign for the shipment tracing variable for the hired truck mode. However, Model 2 better demonstrates the importance of frequency of shipment and reliability of transit time in the decision to use private truck. It may be recalled that the derived variables were obtained from the hypothesis that shippers' perceptions of the importance of transit time and reliability are influenced by the frequency of shipment of the commodity. The results appear to indicate that this hypothesis may be valid. It is observed from the results for the private truck mode that, although reliability by itself was not significant in explaining the choice of the mode, the derived variable frequency times reliability was the more important of the two significant quantifiable factors.

Shipping cost was not found to significantly influence the choice of any mode. This result is somewhat unexpected. The lack of significance of the cost variable may be attributed to one or more of the following factors:

1. The commodities in the survey are not sensitive to transportation cost.
2. There are measurement errors in the cost variable because of lack of precision in the cost information supplied by respondents to the questionnaire.
3. The cost variable is improperly specified. It has been suggested that an alternative specification of the cost variable (such as cost per ton-mile rather than the cost per pound used in this study) might have produced different results. This is a valid point and should be considered by subsequent researchers in this area.

In-transit damage was found to be not significant in all the models. This result is not entirely unexpected. Examination of the data shows that a majority of respondents (68 percent) indicated that no damage or loss occur to their commodities while in transit. Of those who indicated some commodity damage, a large number provided damage estimates that were comparatively small.

Commodity value was rejected in most models because it had limited dispersion. This effect also caused the relative cost derived variable to be rejected in all models. It is not obvious from the data why commodity value has limited dispersion because a large variety of commodities is included in the sample. A possible explanation of this result could be the lack of precision in the values of the variable supplied by respondents.

In many previous surveys of shippers, reliability of transit time was ranked near the top of the list

of factors that influence mode choice. The results of this research show reliability to be especially significant in the decision to use private truck, but it does not appear to influence the choice of any other mode.

Meaningful models could not be produced for the air and mail modes because of limited observations of these modes in the sample.

CONCLUSIONS

The conclusions of this research and some recommendations for further research are

1. Shippers choose different modes for different reasons. The single factor that appears to affect the choice of all modes is transit time, which showed an inverse relationship with the utility of the truck modes and a direct relationship with the utility of the rail mode. This indicates that, as length of haul increases, shippers would, ceteris paribus, tend to move away from the use of truck and toward the use of rail. This result is consistent with observed shipper behavior.

2. Frequency of shipment showed an inverse relationship with the utility of the hired truck mode and a direct relationship with the utility of the private truck mode. This implies that as frequency of shipment increases shippers would, ceteris paribus, tend to move away from the use of hired truck and toward the choice of private truck. This result is as intuitively expected.

3. Reliability proved important only in influencing the decision to use private truck. This implies that for-hire carriers may be able to influence the private versus for-hire decision of shippers by reorganizing their operations to emphasize reliability of transit time delivery and providing greater frequency of service.

4. Shipping cost was not found to be significant in influencing the choice of any of the modes. This unexpected result may be true, or it may have been caused by lack of precision in the cost data supplied by respondents or by an improper specification of the cost variable. Further research on this point is needed.

5. In-transit damage and commodity value were found to have limited dispersion and proved to be not significant in influencing the choice of any mode. This result for in-transit damage is borne out by an examination of the data, but it is not immediately apparent for commodity value.

6. Several level-of-service variables significantly affect the mode choice decision. Provision of pickup services appears to be the most important factor influencing the choice of hired truck, cooperation between shipper and carrier personnel has some influence in the decision to use hired truck, and the shipment-tracing capability of carriers is one of the important factors influencing the choice of rail.

7. Factors that do not appear to have any influence on mode choice include the shipper's experience, the extent of the geographic coverage offered by the carrier, and whether the shipper has reviewed the mode of transportation within the past 12 months.

8. The perceptions of the importance of reliability and transit time by shippers are influenced by the frequency of shipments. Investigations of the mode choice decision should therefore employ the derived variables rather than the direct variables if frequency of shipment is not itself a direct variable in the model.

9. For both the private truck and rail modes the intercept terms had the highest explanatory power, which implies that factors not identified in the research have significant influence on the choice of these modes. It is not immediately apparent whether these unknown factors are purely unquantifiable ones or whether they also include the effects of those variables that were rejected because of either lack of precision in the data or incorrect specification.

10. Disaggregate models of freight transport modal choice can be calibrated using survey data. However, this research indicates that a mail-response questionnaire may not be a good data collection method because of lack of response from shippers and possible lack of precision in the values of the variables.

11. It is recommended that the freight transport modal choice decision be modeled along the lines suggested in this research but using personal interview data, which, in addition to ensuring adequate sample sizes, provide a higher level of accuracy in the measurable factors. Personal interviews would also make possible the exploration of unknown factors that appear to significantly affect the decision to use private truck and the decision to use rail.

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Publication of this paper sponsored by Committee on Freight Transportation Planning and Marketing.