THE UNIVERSITY OF CALGARY

Impact of Transportation Costs on Intercity Freight Flows

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

CALGARY, ALBERTA

SEPTEMBER, 1992

ISBN 0-315-83248-7

THE UNIVERSITY OF CALGARY

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Impact of Transportation Costs on Intercity Freight Flows" submitted by Malgorzata Owoc in partial fulfilment of the requirements for the degree of Master of Science.

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Abstract

The influence of lowering transportation costs on intercity freight flows was investigated. The transportation cost is the shipping cost and is related to transportation system attributes.

A model is developed based on classical economic behaviour: profit maximization of producers. Intercity freight flows were calculated for actual transportation costs, and then for new transportation costs lowered by the same percentage in the entire network.

The freight flow data used in the study were taken from USA Census of Transportation, Commodity Transportation Survey. Using freight rate models and freight flow data, the unit transportation cost functions for rail, TL, and LTL as well as modal share functions as functions of distance were developed.

The model was applied to SIC 249 commodity group (wood products) for production zones and markets located in the Eastern USA. As an example, a 20% reduction in transportation cost resulted in 9.8% increase in total quantity moved.

Acknowledgements

I am indebted to many people and organizations for their assistance in the completion of this research. Dr. Michel Sargious, my supervisor, provided continuing encouragement, direction, and professional advice throughout duration of the research. Mr. Lloyd L. Ash, from Trimac Consulting Services, provided me with information about the Canadian trucking industry. Dr. J. Douglas Hunt, from Department of Civil Engineering, and Dr. Nigel Waters, from Department of Geography, gave me helpful comments and guidance.

I also wish to extend my thanks to the staff of Academic Computing Services. With their help, research leading to this thesis and its production were done entirely on the ACS AIX computer system. Numerous other individuals, including those I only met through electronic mail, contributed to my research.

This task was made possible thanks to financial support from the Natural Science and Engineering Research Council of Canada and my Department of Civil Engineering at the University of Calgary.

Finally, I would like to express my heartfelt gratitude for the patience and understanding of my husband and children throughout the past years of study.

To my beloved husband

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Chapter 1

Introduction

1.1. Overview.

Transportation contributes significantly to the production and distribution costs of goods. Average transportation costs incurred in the production of goods exceed those related to utilities, advertising and promotion. Based on Canadian data, the proportion of transport cost to total production costs can reach 13% in primary industries and 11% in manufacturing.

For domestic sales, more than 22% of goods-producing industries, in terms of value, have transport cost ratios exceeding 10% of producers' price. Over 54% of the value of exported commodities of Canadian goods-producing industries is characterized by having 10%[1] or more of their value at the Canadian border made up of transportation charges. Exports are more "transport cost sensitive" than domestic sales. The strength of many Canadian industries depends on export sales, and high and rising transportation costs dampen the price competitiveness of Canadian goods in foreign markets.

Truck, rail and intermodal transportation are important for the economy. According to Statistics Canada estimates, these industries account for over 57% of gross business income of all freight and passenger transportation. Truck transportation alone earns nearly one-half of the total freight transportation gross business income. Truck, rail, and intermodal transportation industries carry about 65% of total freight tonnage. Most of

1. All the above data are from (Skoulas, 1981).

the Canada–USA trade is served by surface transportation modes.

There is a strong relationship between freight rates and the cost of providing service. There are many factors that influence rates offered for approximately the same service.

For railroads, a large component of cost is fixed, spent on the right of ways, tracks, and equipment. The railroads give very low rates on some types of shipments which, otherwise, would not be shipped at higher rates. Some rail rates are not much higher than the marginal costs of handling shipments.

Rates in transportation depend on the type of commodity. Some commodity characteristics like density, the need for refrigeration, the need for high reliability, or high frequency of service (for small shipment sizes) influence directly the cost of transportation, and also the rates. However, the value of a commodity is an important factor in determining the rate, but it does not influence the cost of transportation.

For this study, the freight rate is considered as the cost of shipping (how much would be paid for providing this service). Later, the cost itself is related to the transportation system attributes, i.e. the attributes of the vehicle, the characteristics of the network, etc.

The influence of some factors on transportation costs is relatively easy to measure. The effect of other factors is more complex and requires extensive cost-benefit analysis studies. The complexity of some freight transportation problems results very often from the huge variety of goods moved and transportation systems available (vehicles and the network).

Freight transportation, in the future is expected to change in terms of requirements, modal balance, and technology. Regulatory reforms, economic conditions, energy and other factors will influence the transportation industry, traffic growth, and characteristics of freight movement. Truck will become a dominant mode of freight transportation even in terms of freight tonnage. Regulatory reforms, free trade, liberalization of weights and dimensions regulations will result in increased traffic of heavy combination vehicles. There is a need to stimulate technological changes and to improve the productivity and safety of Canadian railways and intermodal systems. Railways need to reduce their costs by 20–30% and offer an improved level of service in order to be considered "attractive" in truck-competitive markets. Such cost reductions require substantial technological, operational and management innovations.

1.2. Study Objectives.

The main goal of this study is to investigate the impact of changes in the transportation system attributes on the cost of freight movement as well as the amount of goods moved between cities. Detailed study objectives are listed below:

1. to formulate a model that would be capable of predicting intercity freight flows using available data;
2. to prepare the data needed for application of the model;
3. to calculate intercity freight flows for actual transportation cost;
4. to calculate the change in flows between cities if transportation costs are lowered; and
5. to relate transport costs to the transportation system attributes.

1.3. Content and Organization of Thesis.

Chapter 2 covers the literature review. Section 2.1 contains discussion of freight transportation demand models. All models were divided into 8 groups according to the approach adopted in the study. Section 2.2 discusses modelling the freight rate structure. Part 2.2.1 presents the factors influencing truck and rail rates. Part 2.2.2 consists of short review of existing freight rate models. It also contains a detailed description of the freight rate model used in the present study. Section 2.3 contains a literature review of the methods of lowering transportation costs. Subsequently, four ways of reducing the cost of transporting goods are discussed in parts 2.3.1–2.3.4.

Chapter 3 explains the methodology used in the study. A model is depicted in detail and the method of solving the problem is discussed.

The data used in the study are presented in Chapter 4. Sections 4.1, 4.2, and 4.3 contain information about freight flow data, network data, and economic data respectively. Subchapter 4.4 describes transportation cost data. The methods of lowering transportation cost in the trucking and rail industries are presented in sections 4.5 and 4.6 respectively.

In Chapter 5 the application of the model to wood products (SIC 249 group) is presented. This commodity group is described in detail in section 5.1. Production zones and markets used in the study are listed in section 5.2. Distances between production zones and markets are given in section 5.3. Unit transportation costs between each O-D pair are derived and described in detail in section 5.4. In section 5.5 unit production cost functions for each production zone and selling price functions for each market are specified. Section 5.6 shows predicted flows between production zones and markets for original transportation costs. New flows, for transportation costs reduced by certain percentages are shown in section 5.7. Validation of the model is explained in section 5.8. In subsections 5.8.1 and 5.8.2 the reasonableness test and the comparison with actual flows are performed. The functional relationships between transportation costs and flows as well as total profits and freight flows are derived in section 5.9.

Chapter 6 indicates the value of the study and the need for more research in that area with the emphasis put on the data requirements.

Chapter 2

Literature Review

2.1. Freight Transportation Demand Modelling.

This section presents a review of previous demand simulation studies and the approaches used in them. Relatively little work has been done in the area of freight demand in comparison to the extensive amount of literature on the demand for passenger transportation. The study of freight transportation demand is complicated because of the heterogeneity in shipment characteristics and in types of cargo and shippers. As a result, many studies are difficult to compare because they use different methodologies and types of data. This literature review is organized according to the approach adopted in the study. The research on the freight transportation demand modelling can be categorized into the following eight models:

A. gravity models

B. abstract mode models

C. mode choice models

D. freight network equilibrium models

E. inventory models

F. derived demand models

G. spatial price equilibrium models

H. generalized spatial price equilibrium model.

A. Gravity Models.

Gravity models have been common in the analysis of commodity flows. The basic structure of a gravity model is not different from its structure in the passenger case. The simplest gravity model, such as the one developed by W.R. Black (1972), has the following properties: the flow between two regions is proportional to the total excess supply in the region of origin and the total excess demand in the region of destination and is inversely proportional to some measure of the cost of transportation. The corresponding formula has the following form[1]

$$T_{ij}^k = \frac{S_i^k D_j^k F_{ij}^k}{\sum_i D_j^k F_{ij}^k}$$

where T_{ij}^k = total tons of commodity k produced in region i and shipped to region j

S_i^k = total shipments of commodity k from region i

D_j^k = total demand for commodity k in region j

F_{ij}^k = a friction factor which is equal to a $1/d_{ij}^{\lambda}$, where d_{ij} is the Euclidean distance between region i and region j, and λ is an empirically derived exponent which may vary depending on the commodity group being examined.

Major disadvantages of the gravity models are:

1) they are too aggregate,

2) they are not behavioural models, and

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1. A.K. Kanafani (1983), p. 296

3) they do not explicitly include the basic characteristics of the transportation mode such as price and quality of the transportation service.

The use of gravity models is limited only to predicting aggregate inter-regional flows. A whole class of gravity models can be derived from an entropy model (Wilson, 1970). In such a case a model is not derived on a basis of an analogy with Newton mechanics but on the analogy with statistical mechanics — using the entropy maximization principle.

B. Abstract Mode Models.

Abstract mode models are extension of gravity models. They include not only attraction and impedance variables but also price and quality of the service attributes of the transportation mode. The general form of abstract mode models is as follows[1]

$$X_{ijm} = \alpha \prod_{k=1}^{K} (M_{ik})^{\beta k} \prod_{l=1}^{L} (M_{jl})^{\gamma l} \prod_{m,n=1}^{M,N} (LOS_{ijmn})^{\delta_{mn}}$$

where

X_{ijm} = total freight flows by mode m between two regions i and j,

M_{ik} = measure of socioeconomic activity at region i (K different measures),

M_{jl} = measure of socioeconomic activity at region j (L different measures),

LOS_{ijmn} = level of service attributes for mode m between two regions i and j (total of M different modes available between two regions i and j,

1. B.H. Kim (1987), pp. 13–14

each with N different LOS attributes).

Socioeconomic activities are measured by, for example: population, gross regional product, percentage of labour force employed in a given industry, etc.

Level of service is represented by, for example: travel time, travel cost, reliability, frequency of service, size of shipment, weight of shipment, number of shipments, value of shipment, distance, and number of transportation modes between two regions.

The abstract mode models handle the freight generation, distribution, and modal split. They describe any type of the carrier as a vector of values which specify attributes of a given mode. The model developed by J.S. Drake (1972) is of the abstract mode type. Although abstract mode models constitute an improvement over the gravity models, they also have their disadvantages. Their fundamental weakness is that they treat transportation as an economic good, not as a derived demand. The concept of derived demand is explained further in subsection F.

C. Mode Choice Models.

Mode choice models allocate freight demand in a given market among competing modes. Most of the existing mode choice models have been developed in a probabilistic way, where the conditional mode choice probability functions are estimated against attributes of commodity, mode, shipper, and market.

$$P(m/X_{ij}) = f(C, T, S, M, \varepsilon)$$

where $P(m/X_{ij})$ = probability of selecting mode m given that the total freight flow is X_{ij} between markets i and j,

C = commodity related attributes,

T = level of service attributes of each transportation mode,

S = shipper attributes,

M = market attributes,

ε = an error term.

Commodity attributes C are, for example, value, density, shelf life, fragility, seasonality, etc. Transportation mode level of service attributes T include cost of moving the shipment, travel time, reliability, wait time, and frequency of service. Shipper attributes S comprise among other things supplier location and plant location. Market attributes M are, for example, total consumption and distance.

Most of the above attributes are not quantifiable, and only a subset of them is typically used in mode choice models.

There are basically four major approaches for estimating the mode choice probabilities:

a) linear probability analysis;

b) discriminant analysis;

c) logit model analysis;

d) probit model analysis.

R.B. Breitenbach (1973) developed a mode choice model which uses linear probability analysis.

D.A. McFadden (1974) was among the first to apply a logit model to a passenger mode choice probability study. Since then, the logit model has become an increasingly popular tool for freight mode choice studies. Examples are K.D. Boyer (1977) and R.C. Levin (1978), who applied a logit model to predict freight mode choice. Also H. Hashemian

(1981) used the logit model to formulate a mode choice model for air and truck for small shipments of manufactured goods.

The probit model has been less popular than the logit model because the parameters of the logit model are easier to estimate than those of the probit ones. J.C. Hartwig and W.E. Linton (1974) applied a probit model as well as discriminant and logit model analyses to a freight mode choice problem. The dependent probit model was also used by C.M. Winston (1979) for motor and rail freight. He used the results to study issues related to intermodal competition and regulatory policies such as: value of transit time variables, value of the service quality differential between modes, market elasticities of demand, and the welfare effects of Interstate Commerce Commission rate regulations.

Another approach to mode choice modelling is presented by W.M. Abdelwahab (1991). He formulated a discrete/continuous model for the joint choice of mode and shipment size for truck and rail modes. This model consists of three equations:

— one equation to predict a shipment size by truck,

— another equation to predict a shipment size by rail,

— a third equation to predict the mode choice probabilities (i.e. mode choice model).

The shipment size equations were formulated as linear regression models. The mode choice equation was formulated as a binary probit model with a linear utility function. The specification of his model was characterized by the inclusion of level-of-service attributes (e.g. freight rates, transit time, reliability of transit time, and loss and damage), as well as commodity attributes (e.g., unit value, density, physical state, and requirement for special handling or temperature control). The main source of the data was the 1977 Commodity Transportation Survey.

D. Freight Network Equilibrium Models.

The freight network equilibrium approach to the prediction of freight movements is one which utilizes a network structure to represent these movements. This method focuses mainly on the shippers, carriers and potential carriers. The first significant multimodal predictive freight network model was developed by P.O. Roberts Jr. (1966) and extended by D.T. Kresge and P.O. Roberts Jr. (1971). In this model, applied to the transport network of a developing country (Colombia), links correspond to transport routes and nodes correspond to cities or regions. The model is both multimodal (i.e. highway, rail, air and water modes) and multicommodity. Only the behaviour of the shippers was taken into account. Using constant unit cost, each shipper chooses the shortest path for movements from an origin to a destination, the amount moving between an origin-destination (O-D) pair being determined by a simple distribution submodel. As part of the National Energy Transportation Study (NETS), CACI Inc. developed a multicommodity, multimodal freight network model referred to as the Transportation Network Model (TNM)[1]. The model did not attempt to predict the freight shipment O-D pattern, since transportation demand is fixed in the model. The basic behaviour assumptions of the model are:

1) Freight routing results exclusively from the decision of shippers seeking to find minimum cost paths.
2) The cost on a path is a linear combination of dollar cost, time and energy use.

Above assumptions ignore any roles that carriers play in the routing of freight shipments. Some tests of the model have been reported, although most use only highly aggregated data. These tests indicate an ability to replicate aggregate modal split data. Total link

1. See M.S. Bronzini (1980).

loadings generated by the model have been compared with historical link usage with significantly poor results.

E.R. Peterson and H.V. Fullerton (1975) have proposed a predictive rail network model that employs either Wardrop's First or Second Principle, although they stated that the Second Principle (system optimization) is preferable for modelling freight systems. The model is a mathematical program the objective function of which is constructed from delay measures that depend on aggregate flow volume. The model assumes that demand is fixed and obtained exogenously. It does not explicitly treat multiple carriers or multiple commodities. Tests of predictive capacity against known data are not available.

The rail freight assignment model developed by Z.F. Lansdowne (1981) is not as general in its scope as the other models reviewed here. The model assumes as input a rail-specific trip matrix. It is a unimodal as well as a fixed-demand model. The principles of the models can be summarized as follows:

1) the only routes used will be those that have the minimum number of interlining points;
2) each carrier will use the shortest distance path in his subnetwork;
3) of the eligible routes, the one that maximizes the originating carrier's share of the revenue is the one selected;
4) if there is more than one originating carrier, then the shipment is divided among all these carriers.

These concepts, although not free of problems, are the first attempt at addressing the question of what the shipper-carrier and carrier-carrier interfaces look like (Friesz, 1983) and (Harker, 1987).

A.L. Kornhauser (1979, 1982) developed an interactive model of the freight system in which network cost parameters can be altered in such a way that predicted flows are close to replicating historical flow level on the network. The model contains two submodels, one to address the question of intracarrier routings, and the second for intercarrier movements. It is a unique feature of this model that the difference between movements within a carrier's own network and between carriers' network is made. No model of shippers' behaviour is included.

More examples of predictive intercity freight models are presented in T.L. Friesz (1983). Authors of that paper pointed out that the key unresolved issues with respect to freight network models are:

1) the simultaneous treatment of shipper and carrier decisions,
2) the simultaneous solution of macroeconomic models which generate supplies and demands and the network itself,
3) the treatment of nonmonotonic functions,
4) explicit treatment of backhauling operations,
5) explicit treatment of blocking strategies, and
6) fleet constraints.

E. Inventory Models.

The basic assumptions underlying inventory models for freight demand are that shippers use transportation service in moving their productive inputs and outputs, and shippers' demand for transportation is optimally determined by minimizing only shippers' inventory cost. Inventory cost consists of the cost component pertaining to transportation (logistics cost) and costs pertaining to shippers' inventory process.

W.J. Baumol and H.D. Vinod (1970) expressed total cost as:

$$\begin{aligned} cost &= direct\ shipping\ cost + in\text{-}transit\ inventory\ carrying\ cost \\ &+ ordering\ cost + receiver's\ inventory\ carrying\ cost \end{aligned}$$

Notation used in developing a more explicit form of this expression is:[1]

C = total relevant annual cost

D = total annual demand in inventory and total amount transported per year

r = unit shipping cost

t = average delivery time for a single shipment

s = average time between shipments

u = unit carrying cost of in-transit inventory

w = unit carrying cost of receiver's inventory

a = replenishment order processing cost

i = average inventory level

Q = receiver's base stock order quantity

The direct shipping cost is

$$r \cdot D$$

Carrying cost of in-transit inventory is

$$u \cdot t \cdot D$$

The ordering cost is

1. B.H. Kim (1987), p. 28

$$a \cdot D / Q = a / s$$

The receiver's inventory carrying cost is

$$w \cdot i = w \cdot s \cdot D / 2$$

The safety stock cost is

$$w \cdot k \cdot \sqrt{(s + t + k' \sigma) D}$$

Here the term under the square root is an approximation of a standard deviation of inventory requirements, with k being the number of standard deviations to provide out-of-stock protection at a fixed level, σ being the delivery time variability expressed as a standard deviation, and k' being the number of σ from the mean in the lead time distribution.

Using the above notation:

$$C = r \cdot D + u \cdot t \cdot D + a / s + w \cdot s \cdot D / 2 + w \cdot k \cdot \sqrt{(s + t + k' \sigma) D}$$

r, σ, and t are unknowns characterizing each mode. Q is also unknown, but can be determined from the receiver's inventory policy regarding base stock. Finding, for a specific transport service, the set of r, σ, and t can be simplified as in most cases only a limited number of transport services is feasible. The following procedure is usually suggested. Q is approximated without safety stock being taken into account and inserted into the equations. Then minimization is done for each mode separately, and the most economical mode is chosen — the one which offers the lowest total cost.

J. Benjamin (1990) developed the mode choice model for the distribution of materials by a shipper. The material handling problem was approached as a total logistics problem including preparation of raw materials, storage at the production site, transportation between the production and demand sites, and storage and utilization at the demand points. The decisions to be made by the shipper as included in the model are:

1) the size of the production lot at each production facility and related inventory levels;
2) the amount to be shipped from each production facility to each demand point over the horizon period;
3) the amount to be ordered at each demand point from each supplier during the horizon period;
4) the mode to use for each link in the transport network;
5) the number of transshipment points to use in the transport network.

Each of these decisions must be made so that total logistics costs are minimized. Capacity and requirements constraints were also considered. The problem was formulated as a nonlinear program and local optimal solutions were found.

Inventory models have the following disadvantages:[1]

a) factor substitution between production and logistics decision is not allowed due to minimization of only the short-term logistics cost;
b) the supplier location is assumed to be fixed;
c) derived demand for transportation is only implied due to the fixed production decisions;
d) difficulties in investigating substitutions between modes (lack of appropriate functional form);
e) insensitivity to quality attributes of service.

1. B.H. Kim (1987), p. 32

F. Derived Demand Models.

Derived demand models explicitly consider the transportation service as a factor input to the shipper's production process. The demand for freight transportation is derived from the shipper's total cost function. The works of A.F. Friedlander and R.H. Spady (1980), T.H. Oum (1980), M-J.J. Kim (1984), and B.H. Kim (1987) belong to this category.

A.F. Friedlander and R.H. Spady (1980) developed a short-run variable cost function and its associated input demand equations which are of the form:

$$C_S = C_S(Y, K, M, P_L, P_T, P_R)$$

$$T_S = \frac{\partial C_S(Y, K, M, P_L, P_T, P_R)}{\partial P_T}$$

$$R_S = \frac{\partial C_S(Y, K, M, P_L, P_T, P_R)}{\partial P_R}$$

where

C_S = short-run variable costs

T_S = short-run demand function for truck

R_S = short-run demand function for rail

Y = total output

K = fixed capital input

M = fixed material input

P_L = price of labour

P_T = hedonic price of truck transportation

P_L = hedonic price of rail transportation

In the same study, approximated hedonic prices of truck and rail services were obtained by adding freight rates and linear functions of quality attributes (value, density, length of haul, and size of shipment).

B.H. Kim (1987) noticed that the linear functional forms assumed for hedonic transportation prices seem to be arbitrary.

T.H. Oum (1980)[1] formulated the cost function for a shipper's entire production and distribution activities as:

$$C(Y, P^C, P^T, Z, D) \equiv \min_{X^C, X^T} \sum_{i=1}^{I} P^{C_i} X^{C_i} + \sum_{l=1}^{L} \sum_{m=1}^{M} P_{ml} \cdot X_{ml}$$

subject to the restriction:

$$f(X^C, X^T, Z, D) \geq Y$$

where

f = production technology function

Y = total shipper's output to be transported

P^{C_i} = price of ith input other than transportation service

P_{ml} = matrix representing freight rates (per ton-mile) of M modes on L links

X^{C_i} = production factors other than transportation service (labour, capital)

X_{ml} = ton-miles shipped using mode m on link l

Z_{mnl} = nth quality attribute of mode m on link l

1. pp. 465–466

D_l = length of link l

He formulated four alternative forms of the transportation sectoral unit cost function. These cost functions were specified in the translog form. He also derived corresponding modal revenue share functions; he estimated jointly each system of the cost and share functions by a maximum likehood method, separately for each of the eight commodity groups selected from the cross-sectional data of Canadian inter-regional freight movements during the year 1970. Parameter estimates of the cost and share functions measured the elasticity of substitution and elasticity of demand with respect to freight rates and quality attributes of service.

B.H. Kim (1987) derived the optimal demand for freight transportation within the context of strategic logistics, which is closely related to the cost minimizing behaviour of the firm. With several assumptions about a firm's production technology he expressed unit transportation cost as a function of hedonic prices alone. Hedonic price is a function of the freight rate and quality attributes. He estimated the unit cost function in three alternative models: the translog (TLM), the extended generalized Cobb-Douglas (EGCDM), and the generalized Leontif (GLM), and derived corresponding modal share functions. Hedonic price was in a log-linear form. Then he found estimates for coefficients in a system of four equations[1] separately for each of the twelve commodity groups selected from cross-sectional data of the USA intercity freight movements during the year 1983. The parameter estimates of the cost, share, and price functions measured the elasticity of substitution of demand with respect to the price and quality attributes.

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1. One equation for each of cost and share, and two for hedonic price.

G. Spatial Price Equilibrium Models.

In spatial price equilibrium models, the transportation system is explicitly represented by a network. A network model describes the transportation system as set of nodes and arcs representing the system infrastructure. Nodes represent facilities such as terminals, ports, rail yards, etc. Arcs represent highways, rail lines, waterways, etc. Some measure of costs and level of service attributes is associated with each element of the network.

The spatial price equilibrium model takes into account all the interactions of the producers, consumers, and shippers, but not carriers. Instead of the carriers, cost functions are defined on the elements of the network to represent transportation firms. Spatial price equilibrium model consists of a subset of the nodes in the network being producing or consuming regions. Demand functions are associated with each consuming region, and supply function with each producing region.

The demands for transportation are derived from the market forces across regions. These demands are the result of an equilibration process characterized by two conditions:[1]

a) if there is a flow of commodity x from region A to region B, then the price in A for commodity x plus the transportation cost from A to B will equal the price of commodity x in B;

b) if the price of commodity x in A plus the transportation costs from A to B is greater than the price of commodity x in B, then there will be no flow from A to B.

T. Takayama and G.G. Judge (1964) constructed and solved the quadratic programming problem assuming constant transportation cost with linear supply and demand functions. The model includes multiple commodities.

1. P.T. Harker (1987), p. 16.

Alternatively it becomes a complementary problem when transportation costs are linear functions (Takayama and Judge, 1971).

References to other works devoted to spatial price equilibrium models can be found in P.T. Harker (1987) pages 17–20.

H. Generalized Spatial Price Equilibrium Model.

The model produced by P.T. Harker (1987) is based upon the concept of a spatial price equilibrium and incorporates the behaviour of producers, consumers and shippers. It replaces the simple transport cost function with a behavioural model of the carriers. His GSPEM (Generalized Spatial Price Equilibrium Model) is capable of predicting the prices and quantities of goods in each region, the transport rates which are charged by each carrier, and the routing of freight traffic.

To demonstrate the usefulness of GSPEM he applied his model to the USA coal economy. For each Bureau of Economic Analysis Area (BEAA) a supply and a demand function for coal was estimated giving detailed description of the spatial pattern of the coal market. Then, using the rail and waterway networks developed at Argonne National Laboratory, flows were calculated for the year 1980. Obtained results were similar to historical prices and flows of coal.

P.T. Harker (1987) also describes the use of GSPEM in analysing the impacts of an increase in coal exports and the closing of the three United States coal ports.

Also a wide variety of policy issues can be analyzed easily with GSPEM. The impacts of a rail line abandonment or a port closing can be traced through the changes in the routing of freight traffic, the changes in transport rates, the changes in the regional prices, and quantities of goods.

2.2. Modelling the Freight Rate Structure.

2.2.1. Factors Influencing Truck and Rail Rates.

A large proportion of railroad costs are fixed costs because of the huge investment railroads have made in their right of ways, track, and equipment. The result of this fact is that railroad marginal costs, or "variable costs" as rate makers call it, are thought to be considerably lower than the average, or "fully distributed" costs. Since any shipment charged a freight rate greater than the marginal costs of handling will contribute to the railroad's overhead and profits, the railroads may find it profitable to give very low rates on some types of shipments which, otherwise, would not be shipped at higher rates. While some rates were set below fully allocated cost, many other rates have been set well above it. Competition has cut severely into the traffic with the highest rates, leaving railroads with mostly low-rated traffic. The railroads' perceived low marginal costs, high average costs, and historical monopoly pricing power led to a highly discriminatory rate structure. This structure continues today despite the loss by the railroads of much of their monopoly power.

Rates in the transportation industry tend to increase as a value of the commodity transported increases. Transportation costs constitute a smaller percentage of the total cost for most high priced goods than for most low priced goods. The market for high priced goods will be less reduced by high transportation charges than the market for low priced goods. Commodities having higher elasticities of supply or demand should tend to have lower rates for transportation. The competitive structure of the market for the commodity transported will have an impact on the rates for that commodity.

The cost of carrying a shipment will usually increase with the distance hauled, but less than proportionately, as illustrated further in Figures 5-2 and 5-3, because a significant proportion of the transport cost is a terminal cost. Cost also increases with shipment weight, but less than proportionately due to the economics of handling larger shipment sizes.

Cost of shipping of a particular product varies according to the attributes of the commodity. Density of a commodity has an effect on the volume which a shipment consumes in a transport vehicle, and consequently on the cost of carrying it. Special handling requirements, such as refrigeration, shock protection, and livestock feeding, add to the cost of a shipment. Level of service provided will clearly influence carrier cost. Fast, dependable service may cost more to provide than slow, unreliable service. Freight rates may also vary between regions of the country because both competitive factors and carrier costs may vary among regions.

2.2.2. Freight Rate Models.

There have been many attempts to model the rate structure[1]. A. Morton (1969) was studying the relationship between rate and length of a haul, as well as between rate and shipment size for truck and rail shipments. A variety of functional forms were tried, however the best results were obtained with

$$\textit{revenue per ton-mile} = a\,(\textit{weight})^{b} + c$$

or

1. Quoted after R.D. Samuelson (1977) pp. 50–51.

$$revenue\ per\ ton\text{-}mile = a\,(mileage)^{b} + c$$

There are other models presented in R.D. Samuelson (1977), but only the ones used in this study are presented here. R.D. Samuelson (1977), among others, estimated freight rate models for rail, less than truck load (LTL) shipment, truck load (TL) shipments, and truck minimum charge. When using truck models to estimate rates, one difficulty is the decision which of the three models (TL, LTL, or minimum charge) to apply. Where the choice is between TL and LTL, it is recommended to calculate rates using both freight rate models and choose the lower one. When choosing between LTL and minimum charge both LTL and minimum charge should be estimated from the models, and the greater of the two should be taken.

The following variable names are used:

$rate$ = transportation charge in cents per hundredweight

$miles$ = length of haul in miles

$weight$ = weight of shipment in pounds

$value$ = value per pound in 1972 dollars at wholesale prices

$density$ = density in pounds per cubic foot.

The discrete elasticity truckload model was found to be:

$$\ln(rate) = 11.567 + 0.261\cdot\ln(miles) + 0.425\cdot\ln(miles/250)$$
$$-0.823\cdot\ln(weight) + 0.791\cdot\ln(weight/30000) + 0.0920\cdot\ln(value) - 0.0925\cdot\ln(density)$$

A term $0.425\cdot\ln(miles/250)$ is included only for distances greater than 250 miles. The term $0.791\cdot\ln(weight/30000)$ is included for weight greater than 30,000 pounds.

The discrete elasticity LTL model was found to be:

$$\ln(rate) = 5.45 + 0.305 \cdot \ln(miles) + 0.166 \cdot \ln(miles/500)$$
$$- 0.156 \cdot \ln(weight) + 0.0233 \cdot \ln(value) - 0.169 \cdot \ln(density)$$

The discrete elasticity rail carload model was found to be:

$$\ln(rate) = 8.89 + 0.438 \cdot \ln(miles) + 0.233 \cdot \ln(miles/300)$$
$$- 0.633 \cdot \ln(weight) + 0.311 \cdot \ln(weight/80000) + 0.166 \cdot \ln(value)$$
$$+ 0.213 \cdot L + 0.177 \cdot G - 0.198 \cdot D_1 - 0.203 \cdot D_2 - 0.0135 \cdot D_3 - 0.178 \cdot D_4$$

where the term $0.233 \cdot ln\,(miles/300)$ is present for distances greater than 300 miles, and the term $0.311 \cdot \ln(weight/80000)$ is present for weight greater than 80000 pounds. Also

L = dummy variable for a liquid, $L = 1$ if commodity is a liquid, $L = 0$ otherwise,

G = dummy variable for a gas, $G = 1$ if commodity is a gas, $G = 0$ otherwise,

D_1 = dummy variable for destination in the "Official Territory" as defined by the I.C.C., $D_1 = 1$ if the destination is in the Official Territory, $D_1 = 0$ otherwise.

D_2 = dummy variable for destination in the "Southern Territory" as defined by the I.C.C., $D_2 = 1$ if the destination is in the Southern Territory, $D_2 = 0$ otherwise.

D_3 = dummy variable for destination in the "Western Trunk Line Territory" as defined by the I.C.C., $D_3 = 1$ if the destination is in the Western Trunk Line Territory, $D_3 = 0$ otherwise.

D_4 = dummy variable for destination in the "Southwestern Territory" as defined by the I.C.C., $D_4 = 1$ if the destination is in the Southwestern Territory, $D_4 = 0$ otherwise.

2.3. Methods of Lowering Transportation Costs.

There are several methods discussed in the literature that can be used to lower transportation costs. Some of these methods are presented in this section.

2.3.1. Application of Advanced Traffic Management for Truck and Rail Movements.

One example is the Strategic Transportation Analysis (STAN). It is an interactive graphic multi-mode multi product system for national or regional strategic planning of freight transportation. The model may be easily adapted to a large range of transportation systems and may be used for various evolutionary scenarios. The primary role of such a model is the evaluation and comparison of alternatives at a strategic level of planning over a relatively long planning horizon. These alternatives represent major changes to the transportation infrastructure (building new modal or intermodal terminals, constructing new rail lines, improving or abandoning existing ones etc.). They can also include important modifications to operating characteristics (e.g. speed, traction type, engine energy consumption figures, etc.) or cost structures (for energy, personnel, equipment, maintenance and operation, etc.).

Scenarios may also represent anticipated or predicted modifications to the magnitude and distribution of demand that may result from variations in the economic environment, in government policies, and other factors.

In the model, a rail transportation system is represented by: its main infrastructure (ownership, gauge and number of tracks, traction type, yard locations, line and yard capacities, etc.) and operation (congestion, delays, costs, etc.). Also the characteristics of the system as well as the main freight flows transported by rail should be included. Such a model demonstrates its great modelling flexibility and practical value.

Recent years have seen a renaissance of North American railroads both in terms of economic indicators (ton-miles, revenues) and the development of communication, information, navigation, and electronic control systems. Increased traffic volumes, new technologies, and stronger competition have put pressure on railway companies to improve the level of their service. The pressure to increase the reliability of arrivals and the use of advanced technologies have forced North American railroads to adhere more closely to a scheduled mode of operation. The purpose of SCAN (Jovanovic, 1991) is to help in the design of robust (reliable) train schedules. The SCAN methodology takes a shorter term view of the problem through the assumption that schedules already exist and that the scheduler's role is to modify the existing schedules or to add and delete trains in order to increase reliability and capital utilization.

There are important interactions between decisions on sizing a vehicle fleet and decisions on utilizing that fleet. The model presented by G. J. Beaujon and M. A. Turnquist (1991) is useful in identifying good strategies for the sizing of vehicle fleets and for the allocation of empty cars. Their research attempts to integrate vehicle fleet sizing decisions with optimization of vehicle utilization. By having direct impact on the level of investment in capital resources, the potential benefits from improved utilization of vehicles is much larger than from simply reduced operating costs (empty vehicle miles, etc.).

Knowledge Based Expert System (KBES) for Intelligent Vehicle-Roadway System projects are advanced systems for surveillance control and management of integrated freeway and arterial networks. Their goal is to reduce congestion, reduce travel time and provide higher level of service (Ritchie, 1990). KBES technology can also provide route guidance (selection) information (Taylor, 1990).

2.3.2. Improvement of Vehicle Fuel Economy.

Vehicle fuel economy may be improved through the use of front-wheel drive, four-speed automatic transmissions, engine improvements such as four-valve designs, reduced friction, lean-burn fast burn combustion, electronic control, reduction in parasitic losses, aerodynamic and rolling resistance reductions, and material substitution.

Drag resistance is an important factor in fuel consumption. For example, the drag resistance for a 38-tonne tractor semitrailer on a level road constitutes 40% of the total movement resistance. Tractor-semitrailer units have their drag coefficients about 1½ times those of cars, while the coefficients for trucks and trailer units are about double.

Unlike the car, the shape of a commercial vehicle is determined mainly by the cargo space. Cuboid, sharp-edges bodies predominate. Statutory size limits impose restrictions on this requirement, and little scope remains to the aerodynamist for changing the shape of the load-carrying part of the vehicle. However, there is some freedom in designing the front end of the vehicle or the cab and developing drag-reducing add-on devices.

The drag of the motor truck is reduced most of all by the vortex stabilizer, while rounded edges on the trailer front chiefly reduce the trailer's own drag. Aerodynamic knowledge has been integrated in a body concept of a tractor-trailer designed for long distance haulage.

By the sequence of improvements — leading edge radii on body front, 'dragfoiler' on cab roof, frontal air dam, chassis fairings for tractor and semitrailer, and cab side flaps — the drag coefficient was reduced by 35% from 0.65 to 0.42.

In addition, on the ordinary rigid truck, energy-saving and performance-improving aerodynamic features are gaining ground. They are particularly effective on light trucks with relatively large bodies with high average speed; drag coefficient was improved here by 36% from 0.78 to 0.5.

2.3.3. Use of New Types of Fuels.

The United States cannot produce enough petroleum to supply domestic demand and is becoming increasingly dependent on imported oil. The petroleum problem is predominantly a transportation problem because it is consuming a growing share of oil. In the United States, the transportation share of oil increased from 53% in the mid 1979 to 63% in 1987 (Sperling, 1989).

The US economy is highly dependent on insecure oil suppliers (40% of all petroleum consumed in the United States is now imported). The absence of substitute fuels that would otherwise restrain increases in the price of oil makes it important to direct more funding for research into the field of alternative transportation fuels.

The two most attractive alternative transportation fuel options in the United States will probably be methanol (made from inexpensive natural gas found in remote areas of the world) and compressed natural gas (gas compressed at fuel stations for storage in vehicles at about 3000 psi, and found in North America and in other foreign sources). These two options are most attractive because of the big amounts of gas that are now being found around the world, including the United States. In certain places in the world, but not in the United States, ethanol fuel from biomass and petroleum-like liquids from tar sands are also attractive alternatives in the near future.

Longer term options that are too expensive to produce now at current or near-term resource prices and with current technology are methanol from coal and biomass, ethanol from biomass, and hydrogen.

2.3.4. Increase of Vehicle Capacity.

There are many ways in which efficiency in transporting freight can be improved. One promising method for increasing the efficiency of the freight transportation system is through the use of larger and more productive vehicles. In recent years, there have been important technical and regulatory developments in several countries which have led to a growth in the use of vehicles which are larger than conventional articulated vehicles.

Longer Combination Vehicles (LCV) used in the Western United States are the Rocky Mountain double, the Turnipike double and the triple trailer combination.

The Rocky Mountain double consists of a three axle tractor pulling a 14.6 m semitrailer and a 8.5 m full trailer. Gross weights can reach 50,000 kg with seven axles.

The turnpike double consists of a three axle tractor pulling a 13.7 m or 14.6 m semitrailer and a trailer of a similar length. Gross weights can reach 58,500 kg with nine axles.

The Triple combination usually consists of a two axle tractor pulling a 8.5 m semitrailer and two 8.5 m trailers. Gross weights can reach 52,000 kg.

Higher productivity can be achieved by the use of LCV. For a movement of the same quantity of goods, fewer trips need to be made. As a result, the number of vehicle-miles per tonne moved could be decreased. Data from Western United States indicate big reductions in carrier fleet (up to 25%) and savings (up to 20%) of miles travelled, when projected nationally (Geuy, 1989). As an example, one bulk cement carrier reduced its rates by 14% due to the use of LCV equipment in the test.

Fuel is a significant cost factor to truck operators. Tests performed in Montana showed that triples can save 27% of fuel consumption over twin trailers. Similar results were found in Utah (25%) and Wyoming (23%). By the use of more LCVs, a decrease in side effects on pavement and bridges could be expected. For example, the Triples exert 26%

less axle weight effect, measured in equivalent standard axle loads (ESAL), per ton hauled than doubles on flexible and rigid pavements at the 105,500 lb (47,854 kg) GCW loading. At the same 105,500 lbs load, the impact of turnpike doubles on pavements is up to 62% less than the tractor semitrailer. A computer analysis of four bridge types, representing of many structures in the West, has been undertaken. Each bridge had three different span lengths. Each analysis confirmed the superior performance of the Triples and Turnpike doubles when measured against the bridge design vehicle or the tractor semitrailer. This study concluded that the use of LCV's would extend bridge life and reduce maintenance costs.

Chapter 3

Method of Analysis

3.1. Introduction.

The objective of this study is to investigate the influence of lowering transportation costs on freight flows between cities. To achieve this objective, it was important to develop a suitable model which it is possible to apply and which does not require more data than those available in the literature. The formulation of the model is based on classical economic behaviour: profit maximization of producers.

3.2. Network Approach and Modelling.

The factors that influence intercity freight flows are:

— the demand for a given commodity at its destination,

— its supply at origin,

— supply at other production zones, and

— the transportation network attributes.

The forces that induce freight movement are mainly related to economics. The movement of a commodity on a specific production-market link will depend on other production zones and markets in the study area. Hence, there is a need for dividing the study area into more or less uniform zones. Each zone should be represented by its centroid and the zone characteristics. The zone centroids are then connected by links that constitute a transportation network. In the present study, the links are not described by distances between zone centroids but by the transportation system attributes represented by the transportation cost, which is the amount paid for shipping the commodity.

The approach taken in this study is not a simple distribution problem with a constant total amount of commodity available at the origin and unknown quantities moved between specific O-D pairs. No constraints are put on the quantities produced, moved and sold, except for the non-negative constraint. That does not mean that quantities produced and moved can reach unreasonably large values, because the unit production cost increases for large quantities produced and the price in the market is always a decreasing function of quantities sold. Additionally, production zones and markets are separated by the transportation cost. The commodity will be moved from a given production zone to a market, only when the selling price minus transportation cost and production cost is a non-negative number. For extremely large quantities produced and sold, revenues may not even equal the costs.

In the previous chapter, which covered the literature review, it was shown that among many available routes the one selected is that with the shortest distance. Hence, the zone centroids are connected by the shortest distance links.

The actual shipping cost depends on the commodity type and the study area. Commodity characteristics as well as the network characteristics (modes available, quality of service and the rates offered) determine the choice of the mode of transport. The average cost of shipping the commodity depends on the modal share. The modal share function and unit transportation cost equations for different modes determine the expected transportation cost. The transportation cost can be lowered through improvements in transportation system attributes, but the direct influence of lowering transportation cost in operation of one mode on the mode choice decisions and the rates offered is not studied here. In recent years the improvements in rail technology which lowered operating costs, induced a 15%

drop in grain rates. Cost reduction changes in the trucking industry resulting in lower rates would necessitate a reduction in rail transportation rates influencing innovations in rail transportation.

The model formulated for this study is intended to predict intercity freight flows, without requiring an extensive data base, as such data are almost impossible to obtain due to their high costs and amount of time needed to collect them. It is also kept in mind that the model should be solvable using available techniques and within a reasonable period of time.

Although a very good method for predicting intercity freight flows was presented by P.T. Harker (1987)[1], his approach was not used in this study because of data and computational difficulties. The Harker model was presented in the previous chapter on literature review.

As mentioned before, the main purpose of this research was to examine the influence of lowering transportation cost on the amounts of freight flows between cities. The transportation cost was assumed, in this study, to be lowered by the same percentage in the entire transportation system. However, the model could be used for other schemes whereby the transportation costs are not reduced uniformly.

Hence, an important requirement in formulating the model was that it should allow modification of the unit transportation costs.

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1. Predicted flows were very close to historic patterns.

3.3. Formulation of the Model.

Freight transportation is a derived demand based on economic activities the purpose of which is to make a profit. Each unit of product manufactured in a region and shipped to a market is subject to a unit production cost and a unit transportation cost. Producers will be willing to manufacture and ship products to a certain market, only if marginal sales revenues at that market are greater than or equal to the sum of marginal production cost and the average unit transportation cost. The classical economic behaviour of every producer of any commodity is to seek maximum overall profit. The amount of product a producer can sell in a market is limited, because the production cost, transportation cost, and selling price are not constant. They are functions of quantity produced, shipped, and sold.

The following notations will be used in this chapter:

x_{jk} – flow between origin j and destination k

$x_{j,}=\sum_{k=1}^{m} x_{jk}$ – quantity produced at origin j

$x_{,k}=\sum_{j=1}^{n} x_{jk}$ – quantity sold at market k

$f_j(x_{j,})$ – unit production cost function at origin j

$p_k(x_{,k})$ – unit price at market k

t_{jk} – (average) unit transportation cost between j and k.

hence

$f_j(x_{j,})\cdot x_{j,}$ – total cost of production of quantity $x_{j,}$ at origin j

and

$p_k(x_{,k})\cdot x_{,k}$ – total revenue at market k from sales in quantity $x_{,k}$

also

$t_{jk}\cdot x_{jk}$ – total cost of transporting quantity x_{jk} between j and k.

For N production areas and M markets, profit $\boldsymbol{P}$ of all producers is represented by the following formula:

$$\boldsymbol{P} = \textit{total revenue} - \textit{total production cost} - \textit{total transportation cost} \tag{3-1}$$

or using just introduced notations

$$\boldsymbol{P} = \sum_{k=1}^{m} [p_k(x_{,k})\cdot x_{,k}] - \sum_{j=1}^{n} [f_j(x_{j,})\cdot x_{j,}] - \sum_{j=1}^{n}\sum_{k=1}^{m} t_{jk}\cdot x_{jk} \tag{3-2}$$

Mathematically speaking, the problem is to find the maximum of $\boldsymbol{P}$, with respect to x_{jk}, while the functions f_j, p_k, and t_{jk} are known. The functions f_j, p_k, and t_{jk} are specific to the commodity considered. As unknowns x_{jk} cannot have arbitrary values, they have to be non-negative, because they represent flows. The problem can be formulated as follows:

$$\text{maximize } \boldsymbol{P} \text{ subject to } x_{jk} \geq 0 \tag{3-3}$$

Now a form for functions f_j and p_k has to be specified.

A general formula for unit production cost at origin j, as a function of $x_{j,}$, the quantity produced, is:

$$f_j(x_{j,}) = C_{j2}\cdot x_{j,}^2 + C_{j1}\cdot x_{j,} + C_{j0}, \tag{3-4}$$

where C_{j2}, C_{j1}, and C_{j0} are origin dependent constants. The shape of such a curve is shown in Figure 3-1. A further explanation of this curve is presented in section 4.3.

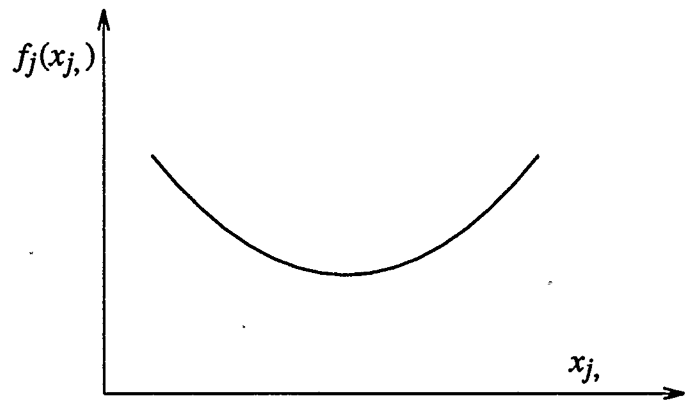

Figure 3-1. A General Shape of a Unit Production Cost Function at Origin j.

For this study, the unit production cost curves used are in the form[1]:

$$f_j(x_j) = a_j\left[\sum_{k=1}^{N} x_{jk} + s_j\right]^2 + b_j\left[\sum_{k=1}^{N} x_{jk} + s_j\right] + c_j \tag{3-5}$$

The coefficients a_j, b_j, c_j, and s_j are defined in section 5.5. This formula will be the one used in the proceeding chapters.

A general formula for the selling price at market k, as a function of $x_{,k}$, the quantity sold is:

$$p_k(x_{,k}) = d_k \cdot (1 + x_{,k})^{-0.1} \tag{3-6}$$

where d_k is a market dependent constant. The shape of such a curve is shown in Figure 3-2. Derivation of the above formulae can be found in H.-C.D. Yu (1981).

1. following H.-C.D. Yu (1981).

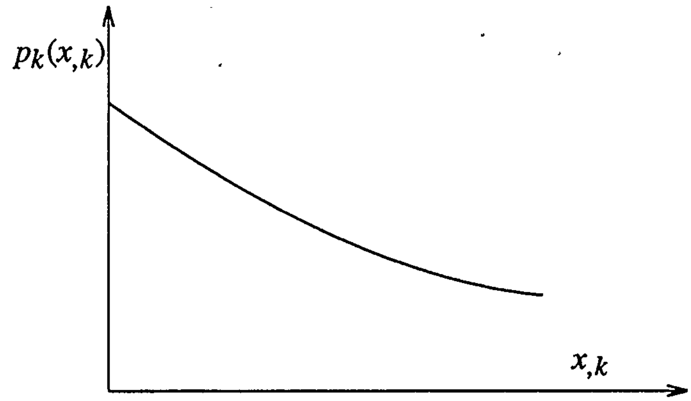

Figure 3-2. A General Shape of a Selling Price Function at Market k.

Since the unknowns of the problem are the flows x_{jk} between production zones and markets, the total profit function expressed in terms of these variables takes the following form:

$$P = \sum_{k=1}^{N}\left[\left(\sum_{j=1}^{M} x_{jk}\right)\frac{d_k}{\left[1+\sum_{j=1}^{M} x_{jk}\right]^{\frac{1}{10}}}\right] - \sum_{j=1}^{M}\sum_{k=1}^{N} x_{jk}t_{jk} - \sum_{j=1}^{M}\left\{\left(\sum_{k=1}^{N} x_{jk}\right)\left[a_j\left(\sum_{k=1}^{N} x_{jk}+s_j\right)^2 + b_j\left(\sum_{k=1}^{N} x_{jk}+s_j\right) + c_j\right]\right\} \tag{3-7}$$

The unit production cost curve is the functional relationship between the quantity produced and the cost of manufacturing one unit of a commodity. Coefficients of the unit production cost function are highly dependent on a commodity group as well as a production zone. Estimation of the unit production cost function requires an extensive amount of economic data. H.-C.D. Yu (1981) calculated the total production cost over the years (from 1971 to 1978), and the corresponding production levels in different locations. Next, he calculated the corresponding unit production costs for each production level and each production zone. Finally, he applied regression techniques to estimate unit production cost functions specific to production zones. Chapter 4.3 contains more information about the above relationships.

To calculate the average unit transportation cost function as a function of distance, a set of freight flow data is required. Transportation cost for each shipment was calculated using freight rate models developed by Samuelson (1977). To apply the above models, specific information about each shipment is required: weight of shipment, density of commodity, value of commodity, as well as distance travelled. Then, depending on the commodity group considered, data should be split into several groups: according to value, depending on mode. For each group unit transportation cost function should be estimated. To get unit transportation costs for a given O-D pair, distance should be entered into the above relationships.

3.4. Mathematical Background.

An optimization problem consists of an objective function and conditions termed the constraints of the problem as they put restrictions on the set of possible values of the problem variables. The solution of an optimization problem is a set of allowed values of the variables for which the objective function assumes an optimal value. In mathematical terms, optimization usually involves maximizing or minimizing. Problems in all areas of mathematics, applied science, engineering, economics, medicine, and statistics can be posed in terms of optimization.

The general form of an optimization problem is as follows:

$$\text{minimize } F(x) \quad \text{for } x \in \boldsymbol{R}^n$$

$$\text{subject to } c_i(x) = 0, \;\; i = 1,2,...m'; \qquad (3\text{-}8)$$

$$c_i(x) \geq 0, \;\; i = m'+1, m'+2, ...m.$$

The objective function F and constraint functions c_i are real-valued scalar functions.

For many years, optimization methods were of small numerical complexity and it was possible to consult a research paper, or a monograph and write a computer program to execute the steps of the method. In recent years, there has been tremendous progress in optimization methods and some problems that were considered intractable can now be successfully solved. Recently, developed methods are so complex that it seldom occurs that a typical user has the time to write his own computer program. A person who wishes to solve an optimization problem should not start from scratch and devise his own optimization method but should be able to understand the usage of routines from a mathematical software library, and most importantly should be able to make a correct choice of a solution subroutine. When a match library contains a subroutine which is a realization of a method known to give good results, then the decision process is a fairly easy one.

Several optimization subroutines from mathematical libraries IMSL and NAG were tried. Most of them were able to obtain a solution for small problems (i.e. 4 producing zones and 6 markets). But only one (present in the IMSL mathematical library) was able to find the solution regardless of the choice of a starting point.

Below, the problem and its method of solution is described. That particular method is implemented in the family of subroutines B2OAH, BCOAH, DB2OAH, and DBCOAH from the IMSL mathematical library; DB2OAH was used in the computational part of this thesis.

A general form of the optimization problem in which the constraints are a set of linear inequalities (LIP) is:

$$\text{minimize } F(x) \text{ for } x \in \boldsymbol{R}^n \qquad (3\text{-}9)$$

$$\text{subject to } Ax \geq b.$$

It can be shown[1] that for the point x^* in the LIP the following are the sufficient conditions that this point is a local minimum

$$Ax^* \geq b, \text{ with } \hat{A}x^* = \hat{b};$$

$$Z^T \nabla F(x^*) = 0; \text{ or, equivalently, } \nabla F(x^*) = A^T \lambda^*$$

$$\lambda_i^* \geq 0, \; i = 1, \ldots, t; \qquad (3\text{-}10)$$

$$Z_+^T \nabla^2 F(x^*) Z_+ \text{ is positive definite.}$$

Before a characterization of the feasible points in the neighbourhood of a possible solution is done, it is important to distinguish between the constraints that hold exactly and those that do not. At the feasible point $\hat{x}$, the constraint $a_i^T x \geq b_i$ is said to be active (or binding) if $a_i^T \hat{x} = b_i$, and inactive if $a_i^T \hat{x} > b_i$. The constraint is said to be satisfied if it is active or inactive. If $a_i^T \bar{x} < b_i$, the constraint is said to be violated at $\bar{x}$.

Using the above conventions, $\hat{A}$ is the matrix containing the coefficients of the constraints active at x^*. Applying a similar convention to $\hat{b}$, $\hat{A}x^* = \hat{b}$ follows. Let Z be a matrix whose columns form a basis for the set of vectors orthogonal to the rows of $\hat{A}$.

Let $\hat{A}_+$ contain the coefficients of the active constraints with positive Lagrange multipliers, and let Z_+ be a matrix whose columns span the null space of $\hat{A}_+$.

The i-th row of the $m \times n$ matrix A will be denoted by a_i^T and it contains the coefficients of the i-th linear constraint:

1. For example in (Gill, 1981) pp. 50–51, 68, 71–74.

$$a_i^T = a_{i1}x_1 + \cdots + a_{in}x_n = b_i. \tag{3-11}$$

The active constraints have a special significance because they restrict feasible perturbations about a feasible point. If the j-th constraint is inactive at the feasible point $\hat{x}$, it is possible to move a non-zero distance from $\hat{x}$ in any direction without violating that constraint; i.e., for any vector p, $\hat{x}+\varepsilon p$ will be feasible with respect to an inactive constraint, if $|\varepsilon|$ is small enough.

On the other hand, an active constraint restricts feasible perturbations in every neighbourhood of a feasible point. Suppose that the i-th constraint is active at $\hat{x}$, so that $a_i^T\hat{x} = b_i$. There are two categories of feasible directions with respect to an active inequality constraint. First, if p satisfies:

$$a_i^T p = 0, \tag{3-12}$$

the direction p is termed a <u>binding</u> perturbation with respect to the i-th constraint, since the i-th constraint remains active at all points $\hat{x}+\alpha p$ for any α. A move along a binding perturbation is said to remain "on" the constraint.

Second, if p satisfies:

$$a_i^T p > 0, \tag{3-13}$$

p is termed a <u>non-binding</u> perturbation with respect to the i-th constraint. Since it holds that

$$a_i^T(\hat{x}+\alpha p) = b_i + \alpha a_i^T p > b_i \ \text{ if } \ \alpha > 0, \tag{3-14}$$

the i-th constraint becomes inactive at the perturbed point $\hat{x}+\alpha p$. A positive step along a non-binding perturbation is said to move "off" the constraint.

Let us write the three term Taylor-series expansion of F around the minimal point x^* along a binding perturbation p $(p = Zp_Z)$:

$$F(x^* + \varepsilon Z p_Z) = F(x^*) + \varepsilon p_Z^T Z^T \nabla F(x^*) + \frac{1}{2}\varepsilon^2 p_Z^T Z^T \nabla^2 F(x^* + \varepsilon\theta p) Z p_Z \tag{3-15}$$

where θ satisfies $0 \le \theta \le 1$, and ε is taken to be a small positive number.

The following notation is used for a gradient of a scalar function F

$$\nabla F(x) \equiv \begin{bmatrix} \dfrac{\partial F}{\partial x_1} \\ \cdot \\ \cdot \\ \cdot \\ \dfrac{\partial F}{\partial x_n} \end{bmatrix} \tag{3-16}$$

and for the Hessian matrix of F

$$\nabla^2 F(x) \equiv \begin{bmatrix} \dfrac{\partial^2 F}{\partial x_1^2} & \cdots & \dfrac{\partial^2 F}{\partial x_1 x_n} \\ \cdot & & \cdot \\ \dfrac{\partial^2 F}{\partial x_1 x_n} & \cdots & \dfrac{\partial^2 F}{\partial x_n^2} \end{bmatrix} \tag{3-17}$$

The analytical shape of a particular function in the problem of this study is:

$$\boldsymbol{P} = \sum_{k=1}^{N} \left[\left(\sum_{j=1}^{M} x_{jk} \right) \frac{d_k}{\left(1 + \sum_{j=1}^{M} x_{jk} \right)^{\frac{1}{10}}} \right] - \tag{3-18}$$

$$- \sum_{j=1}^{M} \sum_{k=1}^{N} x_{jk} t_{jk} - \sum_{j=1}^{M} \left\{ \left(\sum_{k=1}^{N} x_{jk} \right) \left[a_j \left(\sum_{k=1}^{N} x_{jk} + s_j \right)^2 + b_j \left(\sum_{k=1}^{N} x_{jk} + s_j \right) + c_j \right] \right\}$$

As shown above, the method chosen requires that a gradient and a Hessian of an objective function is provided to the program. So the gradient of the objective function of this study was calculated and is presented below.

$$\frac{\partial P}{\partial x_{rq}} = \frac{d_k}{\left[1+\sum_{j=1}^{M} x_{jk}\right]^{\frac{1}{10}}} - \left[\sum_{j=1}^{M} x_{jq}\right] \frac{d_k}{10\left[1+\sum_{j=1}^{M} x_{jk}\right]^{\frac{11}{10}}} \tag{3-19}$$

$$- t_{rq} - a_r\left[\sum_{k=1}^{N} x_{rk} + s_j\right]^2 - b_r\left[\sum_{k=1}^{N} x_{rk} + s_j\right] - c_r - \left[\sum_{k=1}^{N} x_{rk}\right]\left[2a_r\left[\sum_{k=1}^{N} x_{rk} + s_j\right] + b_r\right]$$

Similarly, the Hessian of the function considered is

$$\frac{\partial^2 P}{\partial x_{mn}\partial x_{rq}} = -2\,\delta_{rm}\left[2\,a_r\left[2\sum_{k=1}^{N} x_{rk} + s_j\right] + b_r\right] \tag{3-20}$$

$$-2\,\delta_{qn}\left[\frac{d_k}{10\left[1+\sum_{j=1}^{M} x_{jk}\right]^{\frac{11}{10}}} - \left[\sum_{j=1}^{M} x_{jq}\right]\frac{d_k}{100\left[1+\sum_{j=1}^{M} x_{jk}\right]^{\frac{21}{10}}}\right]$$

here, δ_{ij} denotes a Kronecker delta, it is 1 every time $i = j$ and 0 otherwise.

Optimization programs in the IMSL program library are searching only for a minimum of an objective function. Because the objective function of this study (profit) should be maximized, the objective function, its gradient, and its Hessian should be entered into the optimization program with minus signs.

In most of the optimization methods, only a local minimum can be guaranteed to be found. Global searches are increasingly difficult with the growing dimension of a problem. One of the ways of looking for a global minimum is to start searches at many different points, so possibly the different local minima can be found and compared.

Chapter 4

Description of Data

4.1. Freight Flow Data.

Data taken from the 1977 Commodity Transportation Survey of Census of Transportation (*Census*, 1981) conducted by the USA Bureau of the Census were used for this study. Although a Census of Transportation has been taken every five years since 1963, there were no reliable data after 1977, that could be used for the study[1]. The literature review has not revealed any such comprehensive survey that contains similar disaggregate data in Canada.

A stratified probability sample of 19,500 establishments was selected from all manufacturing establishments having one or more paid employees in the 1977 Census of Manufactures. It provides statistics on the volume and characteristics of commodity shipments by manufacturing establishments in the United States.

Data include the type, weight, value of commodities, shipping mode, zones of origin and destination, distance, and estimated total tonnage represented by each record. The data contains two files. The first one shows origin-destination data for state-to-state commodity flows; the second one shows origin-destination commodity flow data from and to forty nine production zones. Information on origin and destination of each shipment is provided for fifty states and the District of Columbia. For our study the first file was chosen, as it contains more records (1,501,549 compared to 566,475). The detailed

1. Data from 1982 were not published due to poor quality, and 1987 data were not yet available.

description of fields in each record is presented in Table 4-1 and related Table 4-2.

Table 4-1. Field Description for Records on Tape Number One.

Field Name	Field Code Description
(1) File Type:	one-digit code referring to a tape number; value of 1 is assigned to all records on the tape number 1
(2) Origin State – FIPS:	two digit origin state code by FIPS (Federal Information Processing Standard; see Table 4-2)
(3) Origin State – Census:	two digit origin state code by Census Division State Code (see Table 4-2)
(4) Destination State – FIPS:	two digit destination state code by FIPS (see Table 4-2 — the same code as in position 2)
(5) Destination State – Census:	two digit destination state code by Census Division State Code (see Table 4-2 — the same code as in position 3)
(6) Commodity:	five digit Standard Transportation Commodity Code (STCC†) giving description of shipped commodity; the first two digits of a STCC designate the industry to which a commodity belongs‡
(7) Mode of Transport:	one-digit code for identification of major means of transport, defined as the means of transport which carried the shipment for the greatest distance. The following types of carriers were identified: rail — including combinations such as piggyback in which the major distance was travelled by rail; motor carrier — including combinations in which the major distance was travelled by for-hire motor carriers (this category was further defined into carriers which were regulated by the ICC and carriers not under ICC regulations); private trucks — trucks operated by the shipper or the customer; air — including air freight and air expresses and combination in which the major distance was travelled by air;

Table 4-1. Field Description for Records on Tape Number One (continued).

Field Name	Field Code Description
	water — including combinations in which the major distance was travelled by water;
	pipeline — primary shipment of petroleum products from refineries;
	parcel delivery — shipment through the U.S. postal service and other parcel delivery services;
	others — including freight forwarder, when major means of transport was not known, messenger service, own power or towed "shipments" (motorized vehicles, aircraft, and other commodities such as prefabricated buildings, which are towed) etc;
	unknown — used when the principal type of transport is not shown on shipping documents and cannot be readily determined by the respondent
(8) Weight Block:	two-digit number identifying weight-block of the shipment; a total of 21 weight blocks were identified which include shipment sizes ranging from under 50 pounds to over 200,000 and a separate code for unknown shipment weight
(9) Unit Value Block:	two-digit number referring to value per pound of the shipped commodity; for both individual commodities and for the total shipment in CTS, respondents were asked to report the selling price or a comparable value; this was defined as the "net selling value, f.o.b. (freight on board) plant, after discounts and allowances, and exclusive of freight charges and excise taxes"; shipments to other establishments of the same company were to be assigned a full economic value, including all direct costs of production, a reasonable proportion of all costs (including company overhead), and profits; these definitions are the same as the one used in the census of manufacturers.
	A total of 35 value-blocks were identified which include unit values ranging from less than 0.25 to over 100 dollars

Table 4-1. Field Description for Records on Tape Number One (continued).

Field Name	Field Code Description
(10) Expanded Tons:	11-digit number representing the approximate total tonnage represented by that record
(11) Expanded Ton-miles:	12-digit number representing estimated total ton-miles represented by that record (total tons multiplied by straight line miles)
(12) Number of Commodity Records:	actual number of commodity records that were summarized in this record on the basis of common characteristics (items 2, 4, 6-8 above)
(13) Circuity Factor:	the circuity factor appropriate to the combination of origin, destination, and mode of transport represented by this record (for rail and highway shipments only)

† The Bureau of Census uses two coding systems for collecting and publishing data in the Commodity Transportation Survey: the Standard Industrial Classification (SIC) for classifying manufacturing establishments based on their primary activity and the Commodity Classification for Transportation Statistics (TCC) used for classifying the products of manufacturing establishments. The TCC is an approximate commodity adaptation of the SIC, with adjustments being made as are required for transportation. The TCC is nearly identical to the Standard Transportation Commodity Code (STCC) which is maintained by a technical committee composed of representatives from railroad, trucking, and shippers industries.

‡ For example STCC 24 refers to lumber and wood products.

4.2. Network Data.

Network data were taken from Jones (1977). The United States was divided into 120 zones. Detailed description of the zones is presented in Appendix A. The list of nodal cities is presented in Table 4-3.

Table 4-2. FIPS and Division Codes for States.

State	FIPS code	Census Division Code	State	FIPS code	Census Division Code
Alabama (AL)	01	63	Montana (MT)	30	81
Alaska (AK)	02	94	Nebraska (NE)	31	46
Arizona (AZ)	04	86	Nevada (NV)	32	88
Arkansas (AR)	05	71	New Hampshire (NH)	33	12
California (CA)	06	93	New Jersey (NJ)	34	22
Colorado (CO)	08	84	New Mexico (NM)	35	85
Connecticut (CT)	09	16	New York (NY)	36	21
Delaware (DE)	10	51	North Carolina (NC)	37	56
District of Columbia (DC)	11	53	North Dakota (ND)	38	44
Florida (FL)	12	59	Ohio (OH)	39	31
Georgia (GA)	13	58	Oklahoma (OK)	40	73
Hawaii (HI)	15	95	Oregon (OR)	41	92
Idaho (ID)	16	82	Pennsylvania (PA)	42	23
Illinois (IL)	17	33	Rhode Island (RI)	44	15
Indiana (IN)	18	32	South Carolina (SC)	45	57
Iowa (IA)	19	42	South Dakota (SD)	46	45
Kansas (KS)	20	47	Tennessee (TN)	47	62
Kentucky (KY)	21	61	Texas (TX)	48	74
Louisiana (LA)	22	72	Utah (UT)	49	87
Maine (ME)	23	11	Vermont (VT)	50	13
Maryland (MD)	24	52	Virginia (VA)	51	54
Massachusetts (MA)	25	14	Washington (WA)	53	91
Michigan (MI)	26	34	West Virginia (WV)	54	55
Minnesota (MN)	27	41	Wisconsin (WI)	55	35
Mississippi (MS)	28	64	Wyoming (WY)	56	83
Missouri (MO)	29	43			

Table 4-3. Transportation Zone Centroids.

1. Brunswick, GA	21. Tupelo, MS	41. Savanah, GA
2. Jacksonville, FL	22. Columbus, MS	42. Augusta, GA
3. Statesboro, GA	23. Clarksdale, MS	43. Milledgeville, GA
4. Waycross, GA	24. Dyersburg, MS	44. Atlanta, GA
5. Dublin, GA	25. Jackson, TN	45. Chattanooga, TN
6. Valdosta, GA	26. Memphis, TN	46. Huntsville, AL
7. Macon, GA	27. Jonesboro, AK	47. Nashville, TN
8. Cordele, GA	28. Searcy, AK	48. Evansville, IN
9. Albany, GA	29. Harrison, AK	49. Cape Girardeau, MO
10. Lagrange, GA	30. Sikeston, MO	50. St. Louis, MO
11. Columbus, GA	31. Poplar Bluff, MO	51. Quincy, IL
12. Anniston, AL	32. West Plains, MO	52. Columbia, MO
13. Montgomery, AL	33. Lebanon, MO	53. Chillacothe, MO
14. Troy, AL	34. Marshall, MO	54. Des Moines, IA
15. Dothan, AL	35. Sedalia, MO	55. Omaha, NE
16. Decatur, AL	36. Springfield, MO	56. Topeka, KS
17. Birmingham, AL	37. St. Joseph. MO	57. Wichita, KS
18. Florence, AL	38. Kansas City, MO	58. Tulsa, OK
19. Tuscaloosa, AL	39. Nevada, MO	59. Ft. Smith, AK
20. Cotinth, MS	40. Joplin, MO	60. Little Rock, AK

Table 4-3. Transportation Zone Centroids (continued).

61. Greensville, MS	81. Greensville, SC	101. Dallas, TX
62. Jackson, MS	82. Columbia, SC	102. El Paso, TX
63. Meridan, MS	83. Knoxville, TN	103. Austin, TX
64. Mobile, AL	84. Charleston, WV	104. San Antonio TX
65. Pensacola, FL	85. Cincinnati, OH	105. Houston, TX
66. Tallahassee, FL	86. Dayton, OH	106. Salt Lake City, UT
67. Gainsville, FL	87. Cleveland, OH	107. Phoenix, AR
68. Miami, FL	88. Detroit, MI	108. Albuquerque, NM
69. Boston, MA	89. Indianapolis, IN	109. Seattle, WA
70. Albany, NY	90. Chicago, IL	110. San Francisco, CA
71. Buffalo, NY	91. Milwaukee, WI	111. Los Angeles, CA
72. New York, NY	92. St. Paul, MN	112. Charleston, SC
73. Scranton, PA	93. Billings, MT	113. Duluth, MN
74. Harrisburg, PA	94. Denver, CO	114. Springfield, IL
75. Pittsburgh, PA	95. Oklahoma City, OK	115. Toledo, OH
76. Washington, DC	96. Texarkana, TX	116. Columbus, OH
77. Roanoke, VA	97. Shreveport, LA	117. Portland, OR
78. Richmond, VA	98. New Orleans, LA	118. Fargo, ND
79. Charlotte, NC	99. Tampa, FL	119. Grand Rapids, MI
80. Raleigh, NC	100. Amarillo, TX	120. Norfolk, VA

The highway network consists of 120 nodes and 343 arcs. Seven items of information are presented for each highway arc. They are:

1) arc number
2) originating network node number
3) terminating network node number
4) distance in miles between the two nodes
5) travel time in minutes for a truck to move from node to node
6) number of lanes of traffic in both directions, and
7) the route designations for the highways comprising the arc (I = Interstate, US = Federal and primary or secondary, or S = State)

The rail network consists of 120 nodes and 277 arcs. The seven items of information that describe each rail arc are:

1) arc number,
2) origin node,
3) terminating node,
4) arc length in miles,
5) average speed made by the highest class freight train normally traversing the arc,
6) arc capacity in trains per day in both directions; this includes the capacity of all parallel routes considered part of the same arc,
7) railroad company(s) owning the lines comprising the arc.

It also contains detailed data about the water network, but it was not used in this study. Detailed description of data is presented in Jones (1977).

4.3. Economic Data.

To use the model, a unit production cost curve is needed for each production zone. Developing such a curve is a time consuming task and requires extensive amount of data. For the present study, unit production cost curves were taken from Yu (1981). Detailed description of the derivation of unit production cost curves is presented in his work. But some basic ideas and data requirements are given below.

A production cost function is a functional relationship which specifies the production cost at each level of production. Average production costs are not linearly proportional to production outputs. As the plant capacity is reached the average variable costs will rise sharply. The initial decline in average costs is due to the decline in average fixed costs. The eventual increase in average costs is due to the increase in average variable costs. The combination of these two effects yields a U shape for the average cost curve in the short to medium run.

The most useful sources of information concerning location specific industry statistics are the Annual Survey of Manufacturers and the Census of Manufacturers. Some of the important types of information provided by the above publications are described below.

Annual Value of Shipments. The received or receivable annual net selling values, f.o.b. (freight on board) plant, after discounts and allowances, and excluding freight charges and excise taxes.

Annual Cost of Materials. The industry total cost of materials including:

a) the total delivered cost of all raw materials, semifinished goods, parts, components, containers, scrap and supplies put into production or used as operating supplies, and costs for repair and maintenance during that year;

b) the amount paid for electric energy purchased;

c) the amount paid for all fuels consumed for heat, power, or generation of electricity.

Annual Manufacturing Employee Payrolls. It includes the gross earnings paid in the calendar year on the payroll of operating manufacturing establishments.

Annual Supplemental Labor Costs. This total picks up the labor costs other than the manufacturing employee payrolls.

Gross Book Value of Depreciable Assets. This data encompasses all fixed depreciable assets on the books of the establishment at the end of each year. The values represent the actual costs of the assets at the time they were acquired, including all costs incurred in making the assets usable (such as transportation and installation).

Rental Payments for Depreciable Assets. This figure includes rental payments for the use of all items for which depreciation reserves would be maintained if they were owned by the establishment.

End of Year Inventories. This term refers to manufacturers' end of year inventories of finished products, work in process and materials, supplies, fuel, etc., at approximate current costs.

Annual costs of production for an industry group include: annual cost of materials, payroll, supplemental labor costs, depreciation costs, rental payments for depreciable assets, taxes, profits and other costs. Using the Census of Manufacturers and the Annual Survey of Manufacturers data, "value of shipments" can be estimated. Selling price per ton can be estimated using Producer Prices and Price Indices from the Bureau of Labor Statistics and the work of Sharp (1979).

Dividing the "value of shipments" of an industry in the region by the "selling price per ton" of that industry gives an estimate of the total "quantity of production" of that industry in that region. Then, it should be assumed that each data item in the time series is an outcome from the actual production cost function. Next, regression techniques should be applied to estimate the parameters of the function.

4.4. Transportation Cost Data.

The cost of moving the commodity, used in the present study, is the amount paid for shipping that commodity. To obtain shipping costs, freight rate models developed by R.D. Samuelson (1977) and freight flow data were used. There is a strong relationship between the cost of moving the commodity and the amount paid (i.e. shipping cost). Lowering the transportation cost will influence the shipping cost.

In following sections some methods of lowering the transportation cost for truck and rail modes are presented.

4.5. Methods of Lowering Transportation Cost in the Canadian Trucking Industry.

This section is based on information included in the report entitled "Operating Costs of Trucks in Canada" (*Transport Canada*, 1990) prepared by Trimac Consulting Services Ltd. Calgary, Alberta. The factors that influence trucks operating costs are: vehicle configuration, commodity characteristics, hauling distance, degree of utilization, regional area of operation, right-of-way conditions, and driver expertise and attitude. Common operating characteristics were investigated for the various parameters:

a) Vehicle Configuration: two axle straight truck (gasoline and diesel powered), five axle semi-trailer, and seven (or eight) axle tractor-train;

b) Commodity Type: dry freight or bulk

c) Annual Equipment Kilometers Travelled

d) Provincial or Territorial Region of Operation

e) Road Surface (Paved/Gravel).

All analyses presented in the document (*Transport Canada*, 1990) were developed using several assumptions. They are described in detail on pages 6–19 of the above mentioned report.

4.5.1. Improving Fuel Efficiency.

During the time period from 1974 through 1982, when fuel prices were escalating at an unprecedented rate, considerable research was done to improve fuel efficiency in the trucking industry. Energy saving technologies can be summarized in the following:

a) Diesel Engines — They last longer, are more fuel efficient and not as costly to maintain as gasoline engines. These advantages outweigh the higher initial cost of the engine and, in some areas, the need for cold weather starting assistance. Diesel engines are used in long distance traveled by heavy trucks and are being used more and more in medium and light weight trucking operations. The percentage reduction in transportation cost as a result of substituting two axle straight trucks gasoline powered with two axle straight trucks diesel powered are presented in Table 4-4 and Figure 4-1.

b) Aerodynamic Drag Reduction — This is most effective for long haul and high average operating speed. In such situations, drag reduction has been estimated to provide fuel economy improvement of up to 10%. The installation of devices to reduce the effects of aerodynamic drag on trucks and trailers is more and more popular. Several manufacturers have introduced power unit designs with aerodynamic shape considerations.

c) Radial Tires — They have longer life, as a result of the radial tire's resistance to tread squirming and deformation, and less rolling resistance. Longer tire life generates less cost per kilometer. The reduced rolling resistance means better fuel economy.

d) Temperature Controlled Fans — These fans, by being off most of the time, reduce the power requirements of the engine and prolong engine life through better engine temperature control and reduced warm up time. This, in turn, reduces engine power requirements and improves fuel economy.

e) Turbo Charged Engines — Many improvements in truck engines, including high torque designs, have been introduced in recent years. They provide bigger power for less fuel consumption, longer vehicle life and maintenance savings.

Table 4-4. Percentage Reduction in Transportation Cost Resulting from Switching from Gasoline to Diesel Two-Axle Straight Truck†

		distance travelled in a year [km]					
		40,000		80,000		120,000	
		paved	gravel	paved	gravel	paved	gravel
General Freight	minimum	2.83	2.86	3.42	3.61	3.63	3.92
	maximum	5.00	4.81	5.88	6.40	6.87	6.59
	average	3.59	3.54	4.41	4.57	4.94	4.93
Bulk	minimum	2.46	4.49	6.59	6.58	7.41	7.33
	maximum	6.47	6.64	8.96	8.64	9.66	9.66
	average	5.27	5.82	7.68	7.73	8.66	8.56

† prepared using data from (*Transport Canada*, 1990).

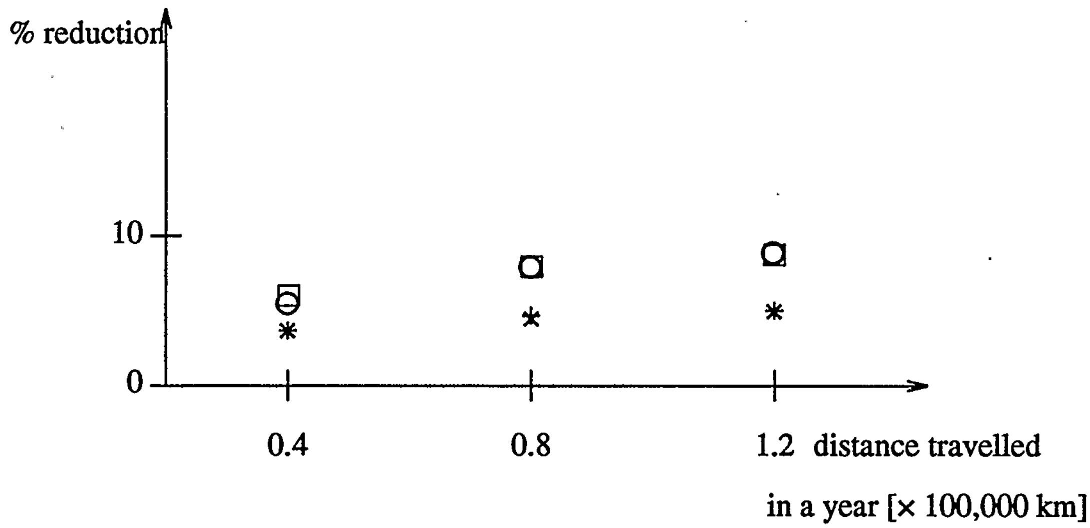

Figure 4-1. Average Percentage Reduction in Transportation Cost as a Result of Switch from Gasoline to Diesel, for Two-Axle Straight Truck
× — general (paved), + — general (gravel), ○ — bulk (paved), □ — bulk (gravel).

4.5.2. Effect of Road Surface on Truck Operating Costs.

Operating costs of trucks driven on gravel roads are higher than those on paved surfaces. The most significant cost differentials occur in the areas of maintenance, life of tires, and driver salary. There is no appreciable difference in fuel consumption of vehicles operating over gravel and paved roads. Administration costs are greater for gravel road operations due to the increased activity caused by the extra maintenance and the additional time to complete a trip.

The increase in average costs due to operation on gravel roads can be summarized in the following:

Driver Costs — for long distance hauling, 8%-12% increase over operations on paved roads,

Repair Costs — 20% increase over operations on paved road — for both tractors and trailers.

Tire Costs — 70% increase over operations on paved roads for power units pulling trailers,

65% increase for trailers, and

43% increase for two-axle straight trucks.

The increase in driver costs is due to the additional travel time. Higher maintenance costs are due to the effect of rougher road surface. The need for maintenance is more common than for paved surfaces. This includes service, parts replacement, oil change, and lubrication. The extra wear on tires caused by operating on gravel surfaces significantly affects tire life and costs. There is a much more frequent need for rotation, recapping, and replacement than for equivalent vehicles operating on paved roads. The reduction in transportation cost resulting from operating on paved roads instead of on gravel roads is presented in Table 4-5, Figure 4-2, and Figure 4-3.

Table 4-5. Percentage Reduction in Transportation Cost Resulting from Switching from Gravel Roads to Paved Roads†

	general freight			bulk		
	distance travelled in a year [km]			distance travelled in a year [km]		
	80,000	160,000	240,000	80,000	160,000	240,000
Two-Axle Straight Trucks — Diesel Powered						
minimum	2.0	2.2	2.2	3.4	3.8	4.1
maximum	3.9	3.8	6.3	4.8	5.4	5.8
average	2.9	2.9	3.3	3.9	4.6	5.1
Two-Axle Straight Truck — Gasoline Powered						
minimum	2.0	2.5	2.2	3.6	4.2	4.4
maximum	3.9	4.2	4.4	4.9	5.3	5.6
average	2.89	3.2	3.3	4.18	4.67	4.98
Five-Axle Semi Trailer Configurations						
minimum	12.5	14.6	15.4	9.0	9.9	13.7
maximum	16.3	18.0	19.3	15.5	17.9	18.9
average	13.88	16.01	16.93	12.64	14.88	15.93
Seven/Eight-Axle Trains						
minimum	13.9	15.6	16.7	8.0	9.8	9.8
maximum	17.1	19.2	24.2	14.1	16.5	18.2
average	15.53	16.06	18.5	11.58	13.82	14.61

† Values in this table were calculated using data from (*Transport Canada*, 1990).

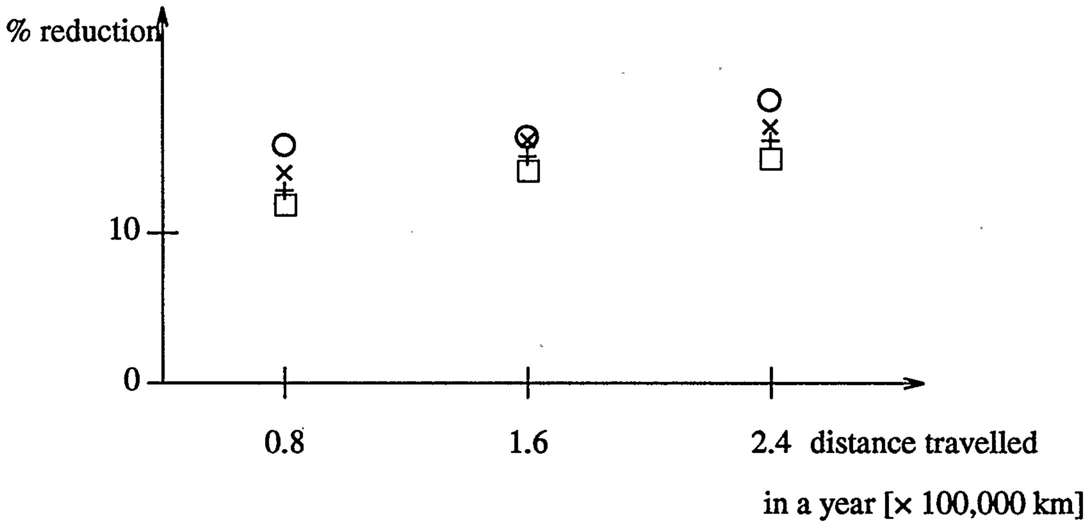

Figure 4-2 Average Percentage Reduction in Transportation Cost as a Result of Switch from Gravel to Paved Roads, for Five-Axle Semi Trailers Configurations and Seven/Eight-Axle Trains

× — general (5 axle), + — bulk (5 axle), ○ — general (7/8 axle), □ — bulk (7/8 axle).

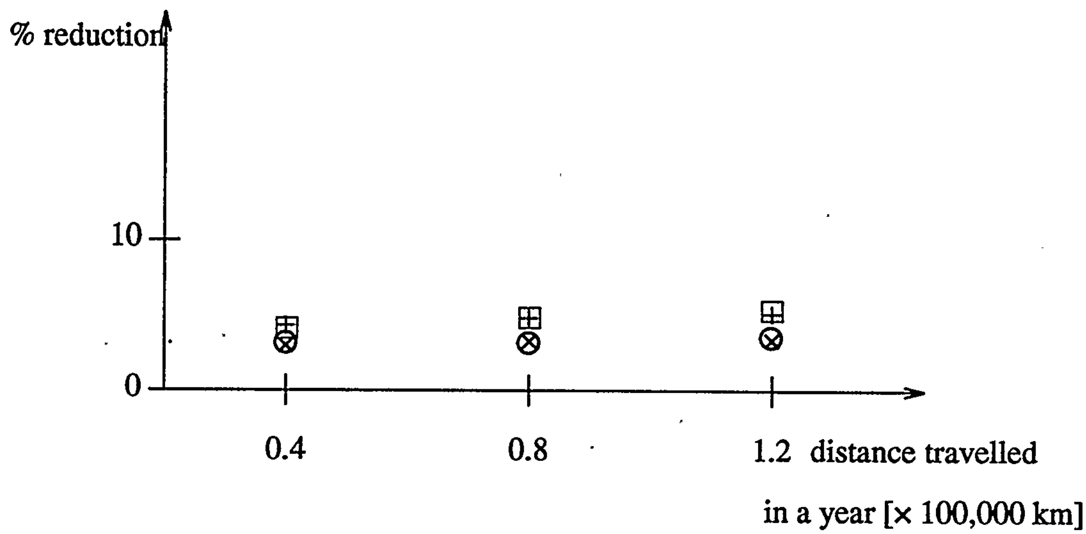

Figure 4-3 Average Percentage Reduction in Transportation Cost as a Result of Switch from Gravel to Paved Roads, for Two-Axle Straight Trucks × — general (gas), + — bulk (diesel), O — general (diesel), □ — bulk (gas).

4.6. Methods of Lowering Transportation Cost in the Canadian Rail Industry.

Railway operating expenses consist of four components:

— way and structures (18.1%)

— equipment (25.4%)

— rail operation (34.1%)

— general (administration, employee benefits, taxes, etc. — 22.1%).

Canadian railways significantly improved their productivity in the past. But still additional improvements are required in the following areas: control systems, automation, operational changes and reduced track maintenance. In Canada, railways have taken steps towards: retrofit technology, enhanced unit train operations, unit train technology improvements, modernization of train control systems, intermodal technology, and information systems.[1]

Energy savings play a major role in reducing operating costs. Many technological improvements are used. One of the recent advances is a rail lubrication system mounted on locomotives or trucks, which brings about up to 7% savings in fuel.[2]

4.6.1. Innovations in Railway Freight Transportation:

Technology improvements fall into the following three subgroups:

A. vehicle/train technology

B. track technology improvements

C. automation, communications, and information systems.

A. Vehicle/Train Technology

A study is being done on the design of the high productivity integral train (HPIT), for use in bulk freight transportation. This concept could save 35% in bulk commodity operating costs and 21% in total ownership and operating costs. This train would feature light weight articulated units (instead of conventional single cars) of aerodynamic design, improved power and braking systems. Potential savings are very attractive and carriers need to acquire sufficient number of such trains to realize potential benefits.[3]

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1. (*Transport Canada*, 1989) p. 44
2. (*Transport Canada*, 1989) p. 44
3. (*Transport Canada*, 1989) pp. 70,72

Large cost reductions in the operation of intermodal trains could be achieved through the introduction of two new train designs:[1]

1) The near-term design has container and trailer variants that offer train operation savings of approximately 20%. The cars are short with two or three axles, having drawbars with slackless couplers. Each car supports one-half of two containers.

2) The advanced design offers origin to destination cost savings of 50% for intermodal freight, in addition to operational flexibility. The train arrangement consists primarily of monocoque car bodies to accommodate containers, distributed propulsion, and a command module to control train operation and single axle radial trucks.

Bulk freight movement is very important for railway carriers and for international trade, so improvements are needed in order to reduce costs and improve service/reliability.

Cost of hauling can be lowered through tare weight reduction and maintenance cost reduction.

Currently coal cars are made of steel. The lightest steel car in use is the "CP Rail bath-tub gondola", which has a tare weight of 24,000 kg. The target weight of an aluminum car is just below 20,000 kg. This four tons difference could be replaced with coal. One such car will be constructed and tested in a standard unit-train operational service for two years. Adoption of this aluminum car could improve the competitiveness of Canadian coal by decreasing transportation costs.[2]

Locomotive fuel saver is a device that automatically stops and starts a locomotive engine. The system saves fuel by shutting down the locomotive engine, rather than allow-

1. (*Transport Canada*, 1985), p. 55
2. (*Transport Canada*, 1991), p. 119

ing it to idle when it is not in use. The engine temperature is monitored — when it cools to 38°C, the engine is automatically restarted and runs until the temperature reaches 55°C. The fuel-saving system can bring about eight thousand dollars of savings per locomotive a year (calculation is based on a fuel cost of 26 cents per litre).[1]

The dual fuel locomotive, now under testing, can bring energy savings. The locomotive will use natural gas with diesel fuel used as the pilot injector fuel.

Self-steering (railway) trucks on railway freight cars significantly reduce wheel wear. Some tests have shown wheel wear is three times lower on self-steering trucks than on conventional trucks. Additional tests are required to demonstrate that the savings accruing from the use of self-steering trucks are sufficient to offset the initial additional costs of the trucks.

B. Track Technology Improvements.

Extending rail life offers lower transportation costs.

Research is being done using conventional rail grinding equipment to develop a ground rail profile which would reduce rail corrugation, shelling, and side wear. The field trials were conducted to formulate rail grinding specification for optimum track curving performance. An asymmetrical ground rail profile design incorporating preventive maintenance to extend rail life in curves and decrease wheel wear and fuel consumption was developed.

1. (*Transport Canada*, 1991), p. 118

C. Automation, Communications, and Information Systems.

Much of current research is being done in automation, communications, and information systems for railway applications. The advanced train control systems (ATCS) are flexible, modular series of computer-communication devices suited to the various terrain and traffic conditions. The overall system can be divided into six major subsystems. The functions served are: train presence detection and location, track and route integrity, ancillary systems interface, switch control, train control, and management of train operators. The features of control and communications required for train movement control combined with management information and automated train scheduling systems will improve the control and management of railways. The ATCS has the potential to save fuel and crew expenses through efficient train speed and routing, improved dispatcher productivity, and better utilization of fixed plant and rolling stock.

Digital communications with on line trains about the condition of locomotive and other train components would result in reduced time required for maintenance and better information for preventative maintenance. No numerical figures were given for reductions in transportation costs due to improvements in automation, communication, and information systems for railways.

Chapter 5

Application, Results, and Validation

5.1. Choice of a Commodity Group.

After studying the data in Canadian and USA sources it was found that the only data which were available at the disaggregate level and which were possible to obtain were related to wood products. For this reason, the model provided in this study is tested for the SIC 249 commodity group which covers the majority of wood products. A detailed description of this group is contained in Appendix B. It should be mentioned here that over 96% of the wood products in the SIC 249 commodity group, which were taken for the present study from the 1977 Commodity Transportation Survey, were within the same unit value category.

A SIC 249 group consists of three subgroups described below.

SIC 2491 — Wood Preserving. Establishments are primarily engaged in treating wood, sawed or planed in other establishments, with creosote or other preservatives to prevent decay and to protect against fire and insects. This industry also includes the cutting, treating and selling of poles, posts, and piling, but establishments primarily engaged in manufacturing other wood products, which they may also treat with preservatives, are not included.

SIC 2493 — Reconstituted Wood Products. Establishments are primarily engaged in manufacturing reconstituted wood products. Important products of this industry are hardboard, particle board, insulation board, medium density fiberboard, waferboard and oriented strandboard.

SIC 2499 — Wood Products, Not Elsewhere Classified. Establishments are primarily engaged in manufacturing miscellaneous wood products, not elsewhere classified, and products from rattan, reed, splint, straw, veneer, veneer strips, wicker, and willow.

5.2. Production Zones and Markets.

Eight origins and seventeen destinations were used in the study. They are located in the eastern part of the United States. Zone numbers are those of the transportation network used by Jones (1977) and all of them are described in Appendix A. Origin (production) zone numbers and their nodal cities are shown in Table 5-1. Destination (market) zones are listed in Table 5-2.

Economic data were available only for these eight production zones and seventeen markets.

Table 5-1. Production Zones

j	Zone Number	Zone Name
1	44	Atlanta, GA
2	48	Evansville, IN
3	50	St. Louis, MO
4	79	Charlotte, NC
5	80	Raleigh, NC
6	83	Knoxville, TN
7	85	Cincinnati, OH
8	87	Cleveland, OH

Table 5-2. Markets

k	Zone Number	Zone Name
1	30	Sikeston, MO
2	38	Kansas City, MO
3	45	Chattanooga, TN
4	49	Cape Girardeau, MO
5	51	Quincy, IL
6	54	Des Moines, IN
7	55	Omaha, NE
8	57	Wichita, KS
9	58	Tulsa, OK
10	69	Boston, MA
11	86	Dayton, OH
12	88	Detroit, MI
13	90	Chicago, IL
14	91	Milwaukee, WI
15	115	Toledo, OH
16	118	Fargo, ND
17	119	Grand Rapids, MI

5.3. Distances between Production Zones and Markets.

Transportation network data for truck and rail were entered to the SYSTEM 2 transportation planning program.[1] Next, using the shortest path distance procedure, truck and rail distances between each production zone and market were obtained.

Truck distances are presented in Table 5-3, while distances by rail are listed in Table 5-4.

5.4. Calculation of Unit Transportation Cost.

This commodity group was moved mainly by rail and truck (only 1% by water and less than 1% by air). For this reason, this study considers only the truck and rail modes.

From the flow data, unit transportation costs are calculated for each origin — destination pair within the states containing these production zones and markets. The procedure used for this purpose is as follows:

First, a multiple regression analysis is used to determine the modal share for rail and truck as a function of distance. It is used as a weighting factor in calculating expected unit transportation cost, when transportation costs by truck and rail are known.

The unit transportation cost for rail was found using multiple regression analysis.

Calculation of transportation cost by truck is more elaborate. Using the procedure suggested by Samuelson (1977), truck data are separated into two groups:

— less than truck load shipments (LTL);

— truck load shipments (TL),

Unit transportation costs for each group are then calculated separately.

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1. SYSTEM 2 is a program by JHK & Associates, 4660 Kenmore Avenue, Alexandria, VA 22304.

Table 5-3. Distances by Truck [miles]

	j	1	2	3	4	5	6	7	8
k	n	44	48	50	79	80	83	85	87
1	30	429	226	185	604	723	365	450	696
2	38	772	413	241	947	1066	708	573	777
3	45	113	286	446	321	470	112	364	610
4	49	411	263	148	586	705	347	440	686
5	51	674	287	115	849	968	610	423	627
6	54	926	551	379	1063	1119	822	570	668
7	55	974	627	455	1149	1251	910	702	800
8	57	884	613	441	1059	1178	820	773	977
9	58	800	550	378	1008	1099	741	717	921
10	69	707	1086	1159	814	715	927	862	631
11	86	528	273	341	513	569	303	51	202
12	88	743	446	514	643	699	518	266	172
13	90	695	296	288	778	834	537	285	342
14	91	782	383	375	865	921	624	372	429
15	115	682	385	453	582	638	457	205	111
16	118	1333	934	863	1416	1472	1175	923	980
17	119	759	407	455	790	846	598	346	319

n is the zone number, as defined in Tables 5-1 and 5-2

Table 5-4. Distances by Rail [miles]

	j	1	2	3	4	5	6	7	8
k	n	44	48	50	79	80	83	85	87
1	30	544	322	157	795	950	563	495	659
2	38	871	429	264	1074	1229	805	602	766
3	45	136	310	475	380	535	111	403	567
4	49	537	294	129	788	943	539	467	631
5	51	739	293	128	938	1093	669	429	593
6	54	983	537	372	1113	1268	844	552	612
7	55	1023	577	412	1222	1377	953	687	747
8	57	1079	653	488	1298	1453	929	826	990
9	58	822	581	416	1073	1228	841	754	918
10	69	1099	1074	1184	848	729	1117	846	682
11	86	544	283	393	616	771	347	55	109
12	88	760	499	556	832	864	563	271	163
13	90	735	289	284	841	996	572	280	340
14	91	821	375	370	927	1082	658	366	426
15	115	704	443	527	776	808	507	215	107
16	118	1361	915	910	1467	1622	1198	906	966
17	119	911	473	468	983	1015	714	422	314

The expected unit transportation cost for trucks as a whole is calculated from the percentages of tonnage moved by LTL and TL. In the study, it was found that the percentages of tonnage moved by LTL and TL do not depend on distance.

Detailed description of freight rate models developed by Samuelson (1977) and used in this study, is already presented in the literature review in Chapter 2 (section 2.2.2).

The formulae used for calculating expected unit transportation cost by truck and rail as function of the distance x are listed below (an adjusted R^2 value is shown for each equation in parenthesis).

The function representing modal share by truck is

$$\text{percentage of weight moved by truck} = -3.153 \cdot 10^{-6} \cdot x^2 - 0.06805 \cdot x + 98.93 \quad (5\text{-}1)$$

This relationship is shown in Figure 5-1.

The formula for unit transportation cost by rail (uc_R) is

$$uc_R = -0.01697 \cdot x + 273.9 - 117.5 \cdot \log(x) + 13.69 \cdot \log^2(x) \quad (5\text{-}2)$$

The unit transportation cost function by rail is presented in Figure 5-2. Plot points in Figure 5-2 have assigned weights, corresponding to expanded tons they represent, for the purpose of regression analysis.

The formula for unit transportation cost by TL (uc_{TL}) is

$$uc_{TL} = -6.888 \cdot 10^{-5} \cdot x^2 + 0.2170 \cdot x + 39.91 \quad (5\text{-}3)$$

Figure 5-3 shows the unit transportation cost by truck (TL).

The unit transportation cost by LTL (uc_{LTL}) has the following functional form:

$$uc_{LTL} = -3.742 \cdot 10^{-4} \cdot x^2 + 365.6 \quad (5\text{-}4)$$

Its graphical presentation is shown in Figure 5-4.

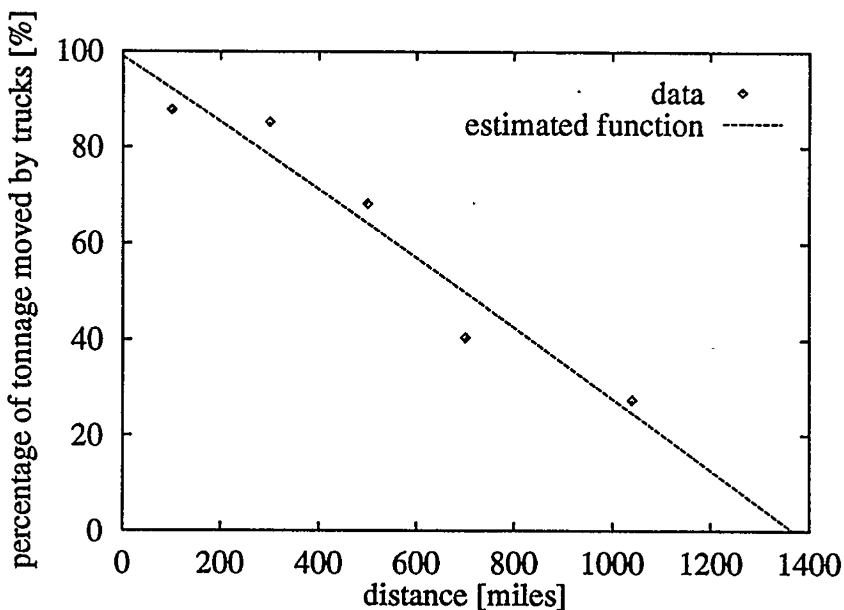

Figure 5-1. Percentage of Tonnage Moved by Truck. ($R^2 = 0.88$)

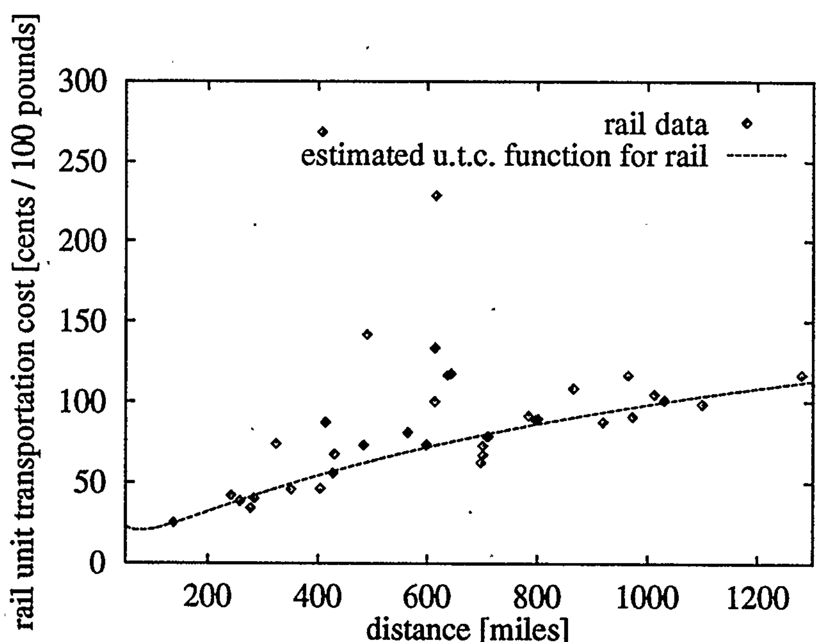

Figure 5-2. Unit Transportation Cost by Rail. ($R^2 = 0.91$)

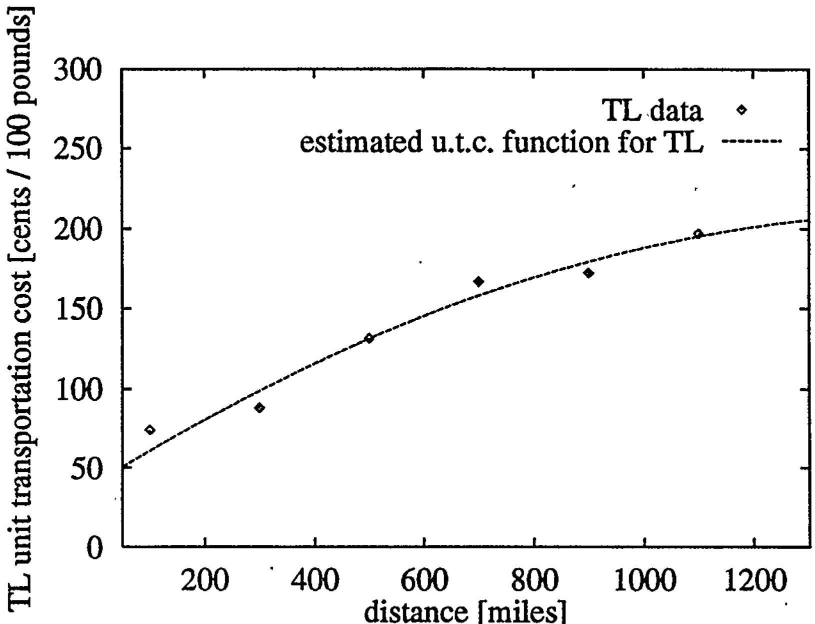

Figure 5-3. Unit Transportation Cost by TL. ($R^2 = 0.97$)

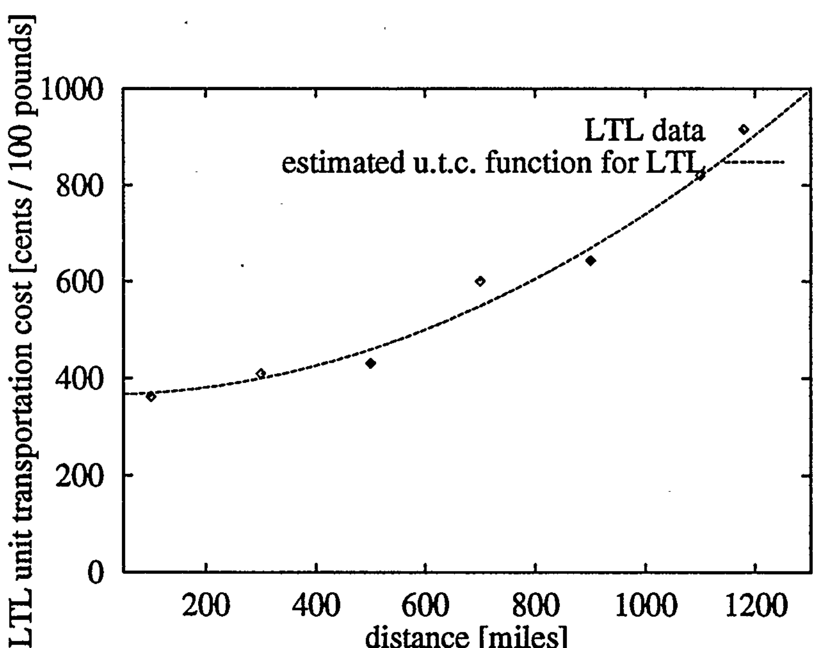

Figure 5-4. Unit Transportation Cost by LTL. ($R^2 = 0.97$)

The percentage moved by LTL, independent of distance, was found to be 4.5%.

Average unit transportation cost for each O-D pair was calculated using the following procedure:

Rail distances from Table 5-4 were entered into equation (5-2) to obtain the unit transportation cost by rail. Also, truck distances from Table 5-3 were inserted into the equations (5-3) and (5-4) representing expected unit transportation cost by TL and LTL. The arithmetic mean of truck and rail distances was entered into the modal share equation (5-1). Then the average unit transportation cost was calculated for each O-D pair. The resulting unit transportation costs are presented in Table 5-5.

5.5. Unit Production Cost and Selling Price Functions.

As stated in Chapter 2, the general formula for the unit production cost function used in this study is:

$$f_j(x_{j,}) = a_j\left[\sum_{k=1}^{N} x_{jk} + s_j\right]^2 + b_j\left[\sum_{k=1}^{N} x_{jk} + s_j\right] + c_j \qquad (5\text{-}5)$$

where $x_{j,}$ is the quantity produced at the origin j (in thousands of tons) and a_j, b_j, c_j, and s_j are origin dependent constants.

Values of the coefficients were taken from Yu(1981) and, for the eight production zones considered in the study, these values are listed in Table 5-6.

The general formula for selling price function is:

$$p_k(x_{,k}) = d_k \cdot (1 + x_{,k})^{-0.1} \qquad (5\text{-}6)$$

where $x_{,k}$ is the quantity sold in the market k (in thousands of tons) and d_k is a market related coefficient. The values of d_k, taken from Yu(1981), are presented in Table 5-7.

Table 5-5. Expected Unit Transportation Cost between Production Zones and Markets [¢ / 100 lb]

k	j	1	2	3	4	5	6	7	8
	n	44	48	50	79	80	83	85	87
1	30	101.79	77.15	70.75	115.90	121.56	96.13	103.08	118.30
2	38	121.82	99.31	78.79	124.18	123.63	119.80	112.44	121.11
3	45	60.06	84.83	102.58	89.48	105.03	60.04	94.33	114.13
4	49	100.14	81.84	65.33	114.97	121.05	94.00	102.00	117.77
5	51	118.16	84.86	60.39	123.24	124.14	114.92	100.22	115.12
6	54	123.65	110.65	95.64	122.93	122.74	122.32	111.89	116.98
7	55	123.60	115.01	102.87	121.70	119.75	123.49	118.69	121.39
8	57	124.47	114.93	102.27	124.27	122.45	122.95	121.48	123.36
9	58	121.89	110.94	95.86	123.55	122.94	120.95	119.63	123.24
10	69	122.90	122.25	121.21	122.26	119.38	124.64	122.67	115.99
11	86	109.25	83.06	91.81	108.91	113.92	87.14	53.52	73.52
12	88	120.35	102.78	108.42	117.92	120.09	108.75	82.11	68.82
13	90	118.83	85.94	84.94	121.68	123.61	110.06	84.55	91.54
14	91	121.60	96.06	95.22	123.25	124.39	115.48	94.88	100.73
15	115	118.15	96.78	103.62	114.64	117.47	103.76	73.65	59.92
16	118	116.94	123.18	123.12	119.81	125.56	120.87	123.16	123.19
17	119	121.93	99.13	103.26	123.06	123.84	114.77	92.60	88.79

Table 5-6. Coefficients of Unit Production Cost Functions

j	Zone Number	Zone Name	a_j [x10^3 ton]	b_j [x10^3 ton]	c_j [x10^3 ton]	s_j [x10^3 ton]
1	44	Atlanta, GA	$0.188 \cdot 10^{-5}$	–0.014	218.94	3,226
2	48	Evansville, IN	$0.188 \cdot 10^{-5}$	–0.014	218.94	3,928
3	50	St. Louis, MO	$0.188 \cdot 10^{-5}$	–0.014	218.94	2,424
4	79	Charlotte, NC	$0.324 \cdot 10^{-4}$	–0.223	565.59	1,667
5	80	Raleigh, NC	$0.324 \cdot 10^{-4}$	–0.223	565.59	3,115
6	83	Knoxville, TN	$0.324 \cdot 10^{-4}$	–0.223	565.59	2,719
7	85	Cincinnati, OH	$0.324 \cdot 10^{-4}$	–0.223	565.59	2,576
8	87	Cleveland, OH	$0.324 \cdot 10^{-4}$	–0.223	565.59	3,445

5.6. Prediction of Flows.

In the previous chapters, all parameters of the objective function were specified. After inserting expected unit transportation costs from Table 5-5 into an optimization program, flows between production zones and markets were obtained. The predicted flows are presented in Table 5-8.

Table 5-7. Coefficient of Selling Price Functions

j	Zone Number	Zone Name	d_k
1	30	Sikeston, MO	360
2	38	Kansas City, MO	417
3	45	Chattanooga, TN	385
4	49	Cape Girardeau, MO	411
5	51	Quincy, IL	375
6	54	Des Moines, IN	439
7	55	Omaha, NE	407
8	57	Wichita, KS	459
9	58	Tulsa, OK	400
10	69	Boston, MA	393
11	86	Dayton, OH	471
12	88	Detroit, MI	466
13	90	Chicago, IL	423
14	91	Milwaukee, WI	377
15	115	Toledo, OH	439
16	118	Fargo, ND	451
17	119	Grand Rapids, MI	416

Table 5-8. Predicted Flows for Transportation Cost = 100% of present cost [$\times 10^3$ ton]

	j	1	2	3	4	5	6	7	8
k	n	44	48	50	79	80	83	85	87
1	30	0	0	81	0	0	0	0	0
2	38	0	0	326	0	0	0	0	0
3	45	0	0	0	0	0	206	0	0
4	49	0	0	320	0	0	0	0	0
5	51	0	0	134	0	0	0	0	0
6	54	0	0	465	0	0	0	0	0
7	55	0	0	0	0	218	0	0	0
8	57	0	0	0	555	151	0	0	0
9	58	0	0	183	0	0	0	0	0
10	69	0	0	0	0	154	0	0	0
11	86	0	0	0	0	0	116	1076	0
12	88	0	0	0	394	0	478	0	0
13	90	0	292	62	0	0	0	0	0
14	91	0	102	0	0	0	0	0	0
15	115	0	0	0	0	0	73	0	430
16	118	0	0	0	618	0	0	0	0
17	119	0	0	0	267	0	0	0	0

5.7. Effects of Transportation Costs on Flows.

Transportation cost used in the model is the cost of shipping the commodity (expected unit transportation cost multiplied by the quantity moved). Expected unit transportation cost function was developed using freight rate models and real flow data containing information about mode of transport, shipment sizes, distances travelled, as well as the type of commodity represented by its unit value as its parameter.

There is a strong relationship between the amount paid for shipping a commodity and the real cost of providing a service. Lowering transportation costs of the transportation system by improvements in vehicle technology and the transportation network will have a direct influence on the rates offered, which represent the transportation cost in the model used.

One of the objectives of the study was to investigate the influence of lowering transportation cost on intercity freight flows. Transportation cost, in the network considered, was lowered by reducing the real average unit transportation cost on all links by the same percentage.

In the model, the unit production cost functions and the selling price in market functions were left unchanged; only unit transportation costs from Table 5-5 were replaced by values which are 10%, 20%, 30%, 40%, and 50% lower. Subsequent flows for lowered transportation costs (for 90%, 80%, 70%, 60%, and 50% of the original costs) are given in Tables 5-9 to 5-13. There is a significant increase in total flows and profits of producers. The percentage increase of total flows and profits is shown in Table 5-14 and in Figure 5-5.

Table 5-9. Predicted Flows for Transportation Cost = 90% of present cost [$\times 10^3$ ton]

	j	1	2	3	4	5	6	7	8
k	n	44	48	50	79	80	83	85	87
1	30	0	0	83	0	0	0	0	0
2	38	0	0	339	0	0	0	0	0
3	45	0	0	0	0	0	206	0	0
4	49	0	0	329	0	0	0	0	0
5	51	0	0	137	0	0	0	0	0
6	54	0	0	491	0	0	0	0	0
7	55	0	0	0	0	228	0	0	0
8	57	0	0	0	586	156	0	0	0
9	58	0	0	193	0	0	0	0	0
10	69	0	0	0	0	161	0	0	0
11	86	0	0	0	0	0	138	1082	0
12	88	0	0	0	454	0	457	0	0
13	90	0	283	87	0	0	0	0	0
14	91	0	107	0	0	0	0	0	0
15	115	0	0	0	0	0	89	0	434
16	118	0	0	0	647	0	0	0	0
17	119	0	120	0	160	0	0	0	0

Table 5-10. Predicted Flows for Transportation Cost = 80% of present cost [$\times 10^3$ ton]

	j	1	2	3	4	5	6	7	8
k	n	44	48	50	79	80	83	85	87
1	30	0	0	87	0	0	0	0	0
2	38	0	0	355	0	0	0	0	0
3	45	216	0	0	0	0	0	0	0
4	49	0	0	341	0	0	0	0	0
5	51	0	0	141	0	0	0	0	0
6	54	0	0	523	0	0	0	0	0
7	55	0	0	0	0	243	0	0	0
8	57	0	0	0	647	146	0	0	0
9	58	0	0	206	0	0	0	0	0
10	69	0	0	0	0	172	0	0	0
11	86	0	0	0	0	0	187	1084	0
12	88	0	0	0	373	0	595	0	0
13	90	0	321	69	0	0	0	0	0
14	91	0	114	0	0	0	0	0	0
15	115	0	0	0	0	0	119	0	434
16	118	0	0	0	688	0	0	0	0
17	119	0	152	0	146	0	0	0	0

Table 5-11. Predicted Flows for Transportation Cost = 70% of present cost [$\times 10^3$ ton]

	j	1	2	3	4	5	6	7	8
k	n	44	48	50	79	80	83	85	87
1	30	0	0	91	0	0	0	0	0
2	38	0	0	377	0	0	0	0	0
3	45	224	0	0	0	0	0	0	0
4	49	0	0	357	0	0	0	0	0
5	51	0	0	147	0	0	0	0	0
6	54	0	0	563	0	0	0	0	0
7	55	0	0	0	0	262	0	0	0
8	57	0	0	0	733	125	0	0	0
9	58	0	0	221	0	0	0	0	0
10	69	0	0	0	0	185	0	0	0
11	86	0	0	0	0	0	257	1084	0
12	88	0	0	0	551	0	491	0	0
13	90	0	418	0	0	0	0	0	0
14	91	0	123	0	0	0	0	0	0
15	115	0	0	0	0	0	161	0	432
16	118	401	0	0	340	0	0	0	0
17	119	0	87	0	236	0	0	0	0

Table 5-12. Predicted Flows for Transportation Cost = 60% of present cost [$\times 10^3$ ton]

	j	1	2	3	4	5	6	7	8
k	n	44	48	50	79	80	83	85	87
1	30	0	0	94	0	0	0	0	0
2	38	0	0	392	0	0	0	0	0
3	45	226	0	0	0	0	0	0	0
4	49	0	0	367	0	0	0	0	0
5	51	0	0	151	0	0	0	0	0
6	54	0	0	594	0	0	0	0	0
7	55	0	0	0	0	279	0	0	0
8	57	0	0	0	805	111	0	0	0
9	58	0	0	234	0	0	0	0	0
10	69	0	0	0	0	197	0	0	0
11	86	0	0	0	0	0	308	1086	0
12	88	0	0	0	688	0	417	0	0
13	90	0	440	0	0	0	0	0	0
14	91	0	131	0	0	0	0	0	0
15	115	0	0	0	0	0	194	0	432
16	118	629	0	0	159	0	0	0	0
17	119	0	128	0	216	0	0	0	0

Table 5-13. Predicted Flows for Transportation Cost = 50% of present cost [$\times 10^3$ ton]

k	j	1	2	3	4	5	6	7	8
	n	44	48	50	79	80	83	85	87
1	30	0	0	97	0	0	0	0	0
2	38	0	0	406	0	0	0	0	0
3	45	226	0	0	0	0	0	0	0
4	49	0	0	375	0	0	0	0	0
5	51	0	0	153	0	0	0	0	0
6	54	0	0	626	0	0	0	0	0
7	55	0	0	0	0	295	0	0	0
8	57	0	0	0	870	101	0	0	0
9	58	0	0	246	0	0	0	0	0
10	69	0	0	0	0	208	0	0	0
11	86	0	0	0	0	0	349	1091	0
12	88	0	0	0	802	0	362	0	0
13	90	0	460	0	0	0	0	0	0
14	91	0	138	0	0	0	0	0	0
15	115	0	0	0	0	0	221	0	435
16	118	807	0	0	25	0	0	0	0
17	119	0	182	0	182	0	0	0	0

Table 5-14. Percentage Increase in Profits and Flows

Percentage of increase in	% of t_{jk}					
	100%	90%	80%	70%	60%	50%
profits	—	6.1	12.5	19.3	26.6	34.3
flows	—	4.0	9.8	17.4	23.5	29.2

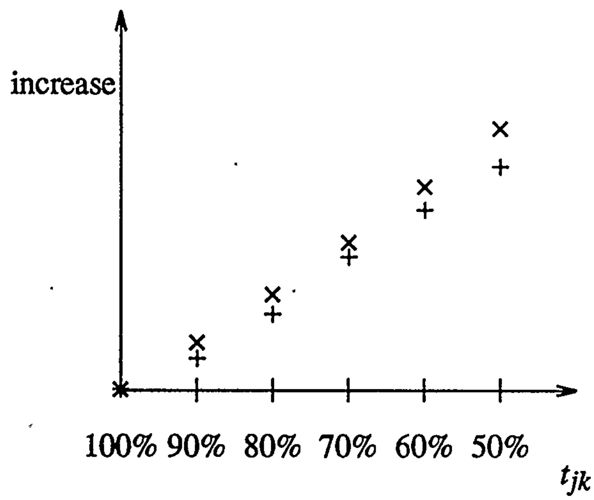

Figure 5-5. Comparison of Profit and Flow Increases

× — profit, + — flow

5.8. Methods of Validation.

The model was applied only to eight production zones and seventeen markets located in the United States of America. Therefore, the flows between 8 production zones and 17 markets were calculated with two assumptions:

— commodity produced in production zones may be sold only to these 17 markets,

— no quantity from other production zones is sold to these markets.

These assumptions make it difficult to compare predicted flows with real ones. But the above assumptions had to be made because of the very limited economic data that is available.

The validation was performed using two methods. At first, a reasonableness test was performed on the model. Secondly, approximate comparison was made between flows predicted by the model and actual flows.

5.8.1. Reasonableness Test.

The main factors influencing the contribution of transportation costs towards the total production cost and distribution depends mainly on the type of commodity produced and the distances between production zones and markets. In the present study, only one commodity group was considered. It is then reasonable to infer that if the production zones and markets are far away from each other, the changes in transportation cost should have higher influence on quantities produced, shipped, and sold than if the production zones and markets are close to each other. The reasonableness test may be applicable only to low cost, non-perishable goods.

Four production zones and six markets separated by higher than average unit transportation cost were chosen for the comparison. They are listed in Tables 5-15 and 5-16. The arithmetic mean of the average unit transportation costs between those production zones and markets was 122 cents/100 pounds compared to 97 cents/100 pounds for the 8 origins and 17 destinations considered in the study. The expected unit transportation cost for each O-D pair indicated in Tables 5-15 and 5-16 is given in Table 5-17.

Table 5-15. Origins

j	Zone Number	Zone Name
1	44	Atlanta, GA
2	79	Charlotte, NC
3	80	Raleigh, NC
4	83	Knoxville, TN

Table 5-16. Destinations

k	Zone Number	Zone Name
1	54	Des Moines, IN
2	55	Omaha, NE
3	57	Wichita, KS
4	58	Tulsa, OK
5	91	Milwaukee, WI
6	118	Fargo, ND

The flows between production zones and markets for the transportation costs given in Table 5-17 are presented in Table 5-18. The flows for lower transportation costs are presented in Tables 5-19 to 5-23.

Table 5-17. Expected Unit Transportation Cost between Production Zones and Markets [¢ / 100 lb]

	j	1	2	3	4
k	n	44	79	80	83
1	54	123.65	122.93	122.74	122.32
2	55	123.60	121.70	119.75	123.49
3	57	124.47	124.27	122.45	122.95
4	58	121.89	123.55	122.94	120.95
5	91	121.60	123.25	124.39	115.48
6	118	116.94	119.81	125.56	120.87

The percentage increases in total profits resulting from lowering the transportation costs for the original problem and those for the four production zones and six markets that have high unit transportation costs are presented in Table 5-24 and Figure 5-6. Similarly, the percentage increases in total flows resulting from lowering the transportation costs are presented in Table 5-25 and Figure 5-7. As expected, there is a significantly higher increase in total flows and profits to producers for the example with four production zones and six markets (i.e. those with high transportation costs) as compared to the original problem with eight production zones and seventeen markets.

Table 5-18. Validation Flows for Transportation Cost = 100% of the actual cost in thousands of tons.

	j	1	2	3	4
k	n	44	79	80	83
1	54	0	51	0	0
2	55	0	226	0	0
3	57	96	3	0	0
4	58	196	0	0	0
5	91	78	0	0	0
6	118	397	0	0	0

Table 5-19. Validation Flows for Transportation Cost = 90% of the actual cost in thousands of tons.

	j	1	2	3	4
k	n	44	79	80	83
1	54	0	57	0	0
2	55	0	250	0	0
3	57	81	29	0	0
4	58	216	0	0	0
5	91	86	0	0	0
6	118	436	0	0	0

Table 5-20. Validation Flows for Transportation Cost = 80% of the actual cost in thousands of tons.

	j	1	2	3	4
k	n	44	79	80	83
1	54	0	0	71	0
2	55	0	0	317	0
3	57	0	0	139	0
4	58	0	0	267	0
5	91	0	0	106	0
6	118	514	0	0	0

Table 5-21. Validation Flows for Transportation Cost = 70% of the actual cost in thousands of tons.

	j	1	2	3	4
k	n	44	79	80	83
1	54	0	0	79	0
2	55	0	0	353	0
3	57	0	0	156	0
4	58	0	0	299	0
5	91	0	0	118	0
6	118	571	0	0	0

Table 5-22. Validation Flows for Transportation Cost = 60% of the actual cost in thousands of tons.

	j	1	2	3	4
k	n	44	79	80	83
1	54	0	0	88	0
2	55	0	0	392	0
3	57	0	0	173	0
4	58	0	0	333	0
5	91	0	0	132	0
6	118	630	0	3	0

Table 5-23. Validation Flows for Transportation Cost = 50% of the actual cost in thousands of tons.

	j	1	2	3	4
k	n	44	79	80	83
1	54	0	0	98	0
2	55	0	0	432	0
3	57	0	0	191	0
4	58	0	0	368	0
5	91	0	0	146	0
6	118	659	46	0	0

Table 5-24. Percentage Increase in Profits

Problem	% of t_{jk}				
	90%	80%	70%	60%	50%
4×6	10.2	22.8	36.6	52.0	69.0
8×17	6.1	12.5	19.3	26.6	34.3

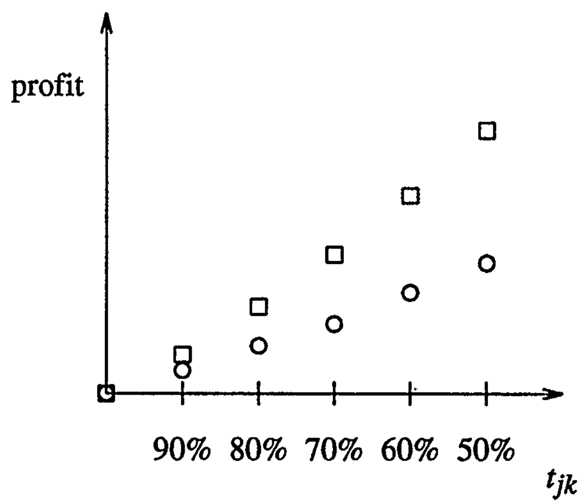

Figure 5-6. Comparison of Profit Increases

□ — 4×6 problem, O — 8×17 problem

Table 5-25. Percentage Increase in Total Flows

Problem	% of t_{jk}				
	90%	80%	70%	60%	50%
4×6	10.3	34.9	50.4	66.9	84.9
8×17	4.0	9.8	17.4	23.5	29.2

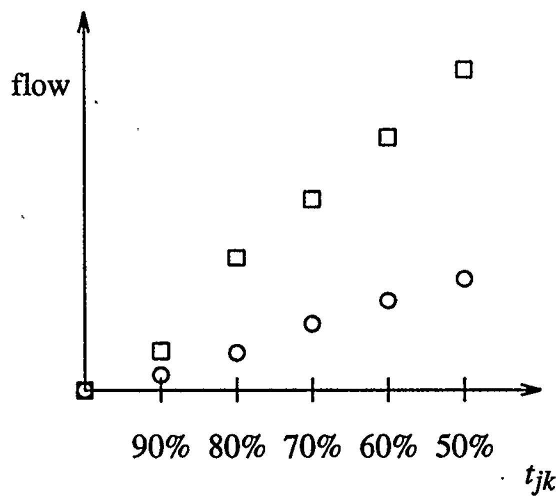

Figure 5-7. Comparison of Flow Increases

□ — 4×6 problem, ○ — 8×17 problem

5.8.2. Comparison with Actual Flows.

As mentioned earlier, the actual flows between production zones and markets are different from the ones predicted because the production from the chosen zones may also be sold to other markets. Moreover, production from other zones may be supplied to the chosen markets. However some approximate comparisons will be performed. The source of the actual flow data is the Census of the Commodity Transportation Survey which provides information about freight movements between states. The majority of the zones used in this study is below state size. The production zones are included in the following 6 states: Georgia, Indiana, Missouri, North Carolina, Ohio, Tennessee. The markets are within 12 states: Illinois, Indiana, Kansas, Massachusetts, Michigan, Nebraska, North Dakota, Ohio, Oklahoma, Tennessee, Wisconsin. From the Commodity Transportation Survey, the real total flow originating in the states that include production zones and terminating in the states containing markets was 36,441,000 tons.

Due to problems with obtaining accurate zone size information an approximate check was done.[1] The objective of this procedure was to check whether flows between zones obtained from calculations are reasonably proportional to flows between states (given in the census data), as compared to the ratio of the areas of the zones to the areas of corresponding states.

The size ratio for production zones was about 30% and for markets was about 58%. Taking into account only areas of production zones and markets compared to areas of states, and neglecting economic factors influencing freight flows, the total flow between pro-

1. BEA's used in the study were delineated in 1969. Since then they were updated twice, and library searches produced only the description of newer data (1977 and 1990 revisions).

duction zones and markets can be expected to be about 17% (30% times 58%) of the flow between states. If this multiplier is applied to the total flows of 36,441,000 tons between states an approximate amount of 6,195,000 tons is obtained. The comparable amount predicted by the model was 6,711,000 tons. Considering all the assumptions and simplifications used in estimating the real flows, the model predictions are satisfactory.

5.9. Regression Models for the Results.

In order to determine a functional relationship between transportation costs and flows, methods of regression analysis were used. Parameters of equations: (1) describing percentage growth in the total profit as a function of percentage of lowering transportation cost, and (2) percentage growth in total flow as a function of percentage of lowering transportation cost, were estimated. Two general functional forms were considered:

$$y = a\,x + b \ \text{ subject to } \ y(0) = 0 \tag{5-7}$$

and

$$y = a\,x^2 + b\,x + c \ \text{ subject to } \ y(0) = 0 \tag{5-8}$$

The condition $y(0)=0$ was imposed so that the graph representing either of these two equations (5-7) and (5-8) passes through the point (0,0). This means that there is no change in total profit (or total flow) when no change in transportation cost occurs. R^2 values for both the linear and parabolic functional forms were very close. Hence, the linear form was chosen for easier interpretation.

The functional form relating the percentage of increase in profit to the percentage decrease in transportation cost is given in equation (5-9).

$$y = 0.6587 \times x \tag{5-9}$$

The estimated equation relating the percentage increase in flow to the percentage decrease in transportation cost is:

$$y = 0.5593 \times x \tag{5-10}$$

where y is the percentage increase in profit or in flow, and

x is the percentage decrease in transportation cost.

Chapter 6

Conclusions

6.1. Summary of Main Findings of Research.

In this study, the complex problem of transportation system attributes and freight flows between cities was presented. The influence of lowering transportation cost on intercity freight flows was investigated. Next, the methods of lowering transportation cost in the trucking and rail industries were discussed. A model capable of predicting intercity freight flows was developed based on classical economic behaviour: profit maximization of producers. The model required unit production cost functions for all production zones, selling price functions in all markets, as well as unit transportation cost values (the cost of moving a unit of a commodity) for each O-D pair.

The model was able to predict changes in freight flows resulting from lowering transportation costs. Intercity freight flows were calculated first for actual transportation costs. After that, they were calculated for transportation costs that were lowered by certain percentages uniformly over the entire network. Subsequently, total flows and total profits to producers for actual transportation costs were compared with those resulting from lowered transportation costs. This comparison shows that, lowering transportation cost in intercity freight movement has a significant influence on the total amount of commodity produced and moved. To illustrate for the study area considered and for the SIC 249 commodity group (wood products), lowering transportation cost by 20% would result in a 9.8% increase in total quantity moved (and produced) and a 12.5% increase in total profit to producers.

These results, looking at the range of changes in total flows and their signs, are as expected and reasonable. Decrease of transportation cost is a stimulating factor for the economy.

However, the results obtained are highly specific to the commodity group being concerned as well as both the productions zones and markets chosen for the study. Notably, all of the functions considered with average unit transportation cost, unit production cost, and selling price depend heavily on the type of goods analysed and the study area.

The factors influencing the cost of transportation depend on vehicle technology and network characteristics. Some of the improvements, like drag reduction, fuel type, and the paving of gravel roads can bring big savings in operating costs of trucks. Drag reduction, most effective for long haul and high average operating speed, can lower transportation cost by up to 10%. Percentage reduction in transportation cost resulting from switching from gasoline to diesel engines can reach 9.7% for two-axle straight trucks operating on gravel roads, and travelling 120,000 km per year. By paving gravel roads, savings in operating costs of up to 24.2% can be expected for seven/eight-axle trucks moving general freight and travelling 240,000 km per year.

6.2. Evaluation of Research Procedures.

In this research, it was possible to develop a model that met the study objectives. This means a model that does not need more data than is available and which can be solved using existing numerical procedures. The model was formulated in such a way that it included unit production cost and selling price functions, and the transportation costs were calculated through multiplying quantities moved by the the link-specific unit transportation costs. Unit transportation costs for each origin-destination pair were values that were easy to modify or lower by a certain percentage in the entire network, or on some selected links only. Since economic data and freight flow data were from the same year, it was possible to incorporate them into the model and later compare the results from the model with real intercity freight flows. Ninety six percent by weight of the commodities included in the group considered were in the same value range. For this reason, there was no need for further disaggregation since this group was considered as uniform. After a considerable preparation of data from the tape that contained a huge amount of freight flow information, it was possible to use available statistical techniques to develop the unit transportation cost relations. Optimum solutions were found using programs from the IMSL FORTRAN library of mathematical subroutines.

In this research, there is a part which could have been done differently: the model formulation, data preparation or the choice of the data set for the study. The model itself was an idealization of real economic relationships and the laws governing them. So although it might be felt that the model could have been expanded, the limitations imposed by the data available precluded any expansions. The problem of the availability of the data can be summarized as follows: its availability at all, time constraints (i.e. additional time to collect and prepare data from various sources), and the cost of its acquisition.

As stated earlier, the influence of lowering transportation costs on intercity freight flows and profits to producers was investigated. In the course of calculations, transportation costs were lowered by 10, 20, 30, 40, and 50 percent in the entire network. The functional relationships between transportation costs and flows were developed based on the results obtained from applying the above specified transportation cost reductions. Alternatively these relationships could be studied using smaller than 10% intervals. Then it would be possible to analyze the results with the greater detail in the range of small transportation system improvements that are more feasible.

6.3. Contributions and Limitations of the Study.

In most of the previous studies, the transportation system was considered to be the bottleneck for freight movement and for economic development of the region. The present study had shown that improvements of the transportation systems attributes are stimulating factors for the economy.

The present research is an example of how to handle large and complex problems. The first task was to either develop models that describe the reality being studied or to select from the subject literature existing models that could be improved to conform to the requirements. Next, due to the many limitations imposed (i.e. time constraints, lack of accurate disaggregate data, or the constraints of existing solution techniques) the most suitable model under these circumstances was selected. Because of all the simplifications made, the results are to be considered approximate. However, one should also be aware that the economy is dynamic and is constantly changing due to global or local policy changes, technology advances, etc. Therefore unless the model incorporates predictions of such changes, it would only describe the static state of the economy. Hence the models implemented in economic studies should not require large time or money investments (due to the complexity of methods used) as the results are always approximate.

This research has also shown that it is worthwhile to look at transportation system improvements not only as a means of providing routes for the movement of goods, but also as a method for enhancing the entire economy of the region or country. Although the numerical findings are for one commodity group only, they are meaningful and the study should be expanded to other commodities. The methods presented for lowering transportation cost, could be used in benefit/cost analyses. Decision makers can look at the results obtained from these analyses and choose cost reductions that are feasible and are cost effective.

6.4. Recommendations for Further Research.

The model was applied only to one commodity group, because of the difficulties associated with obtaining complete data sets. Although the results are highly specific to the commodity group studied, the range of the increase in total flow (and total quantity produced) resulting from lowering transportation cost is significant. In the era of Free Trade Agreement between Canada and United States, with Mexico coming as a third partner, it is very important to offer goods at competitive prices, since about three-quarters of all Canadian exports go across the USA border. To perform such studies, extensive amounts of disaggregate data are required. The major part of the present study was based on USA data after an unsuccessful search for similar data from Canadian sources. Moreover, these USA data were not from recent years, because the newer data were not published due to their poor quality. The unavailability of detailed and reliable data is a major obstacle in this type of study. This indicates the need for a coordinated effort among the various organizations involved in goods movement to have a complete set of data that could be used in analyses of this type.

The important data needed can be briefly summarized in the following:

1) Disaggregate economic data stratified for commodity groups and regions, that are more or less uniform.
2) Transportation data that include information about shipment characteristics similar to those collected in the USA Census of Transportation, Commodity Transportation

Survey, as well as the data about the cost of shipping goods.

3) Network data containing detailed information about all links and different modes of transport.

Having such a bank of data on goods movement is an expensive endeavour that requires adequate funding.

Similar studies should be done for other commodity groups, especially for Canadian exportable goods. To achieve good results, the commodity groups studied should be homogeneous, because the unit production cost and selling price functions as well as transportation cost functions change significantly when the value of a commodity changes. Benefits from the transportation system improvements should be calculated for each commodity group separately, and then summed up after taking into account the percentage of each group in the total quantity moved (produced).

In the study, the model was applied to eight production zones and seventeen markets, located in the Eastern part of the United States of America. The predicted flows between these O-D pairs will be different from the ones that would have been obtained if the entire country is considered. This is mainly because of the interactions with other production zones and markets. In the real world economy, commodities produced in the selected production zones can be sold to other markets, and manufacturers from other production zones may sell their product to the same selected markets. For this reason, the results obtained show approximate changes in the total flow resulting from the modifications in the transportation system attributes. More extensive studies should be undertaken for all production zones and markets in Canada (and USA, and perhaps even Mexico if NAFTA materializes) including ports of export. Then in this case, the predicted flows will be closer to the real ones and the results will be more accurate.

Using the proposed model it was possible to predict the total changes in the intercity freight flows, without assigning flows to specific modes.

To split total flows between modes, the present model can be combined with one of mode choice models, for example with the joint mode choice/shipment size model developed by W.M. Abdelwahab (1991). Because his model was calibrated using the same 1977 data it can be applied to expand on the results from the present model. In this case, the first step is to identify the improvements of the transportation system which are chosen for implementation. The second step is to study carefully their influence on the mode characteristics (such as freight rate, travel time, reliability etc.). The third step, is to calculate aggregated demands for each mode (truck and rail) on every O-D link using the joint mode choice/shipment size model. Finally, using the above relationships and the new unit transportation costs for each mode, the new average unit transportation costs for each O-D pair can be found. Using the model defined in this study, the benefits that are expected from certain improvements can be identified. These benefits can be directly compared with the cost of implementing them.

The factors which influence the unit transportation cost, for a given technology, are unit transportation cost by each mode and the modal share function (the percentage of the total tonnage moved by particular modes). Rates offered by rail are much lower than those of trucks. By improving the travel time and reliability of rail industry, more freight movement could be attracted to that mode, lowering the unit transportation cost.

The model could also be expanded by the inclusion of the in-transit tied-up capital cost, that may be significant compared to transportation costs for high-value commodity groups. While a commodity is being transported, it ties up the capital. The value of a commodity does not increase during its transportation. On the contrary the value of a product may even decrease in the case of perishable goods.

$$\textit{in-transit tied-up capital cost} = \textit{value of commodity being transported} \times$$
$$\times\ \textit{origin-destination travel time} \times \textit{interest rate}$$

It represents lost interest on capital, which is still "in transport" and not yet sold. Origin-destination travel time consists of:

— highway or railway travel time

— terminal times

— maintenance stops time

— driver's rest-stops time.

Additional factors that influence total origin-destination travel time are a daily limit on the number of hours one driver can drive as well as a time limit on the non-stop driving (due to safety considerations). All these factors were accounted for in the freight rates used. The network data provided information only about travel time, based on the average speed, without consideration of truck or rail stop times. Since in the present study, the model was applied to a low value commodity group, in-transit tied-up capital cost was relatively small compared to transportation cost and to the value of the commodity. Hence it was not included in the analysis.

In the model, the total profit of all producers was maximized. This is an approximation of the fact that every producer is trying to maximize only his own profit. For this purpose, each producer has to decide on how much to produce, how much and were to sell, after looking at prices in the markets. The sum of producers' individual behaviours is approximately equal to the behaviour of one big company having an output equal to the total of that of those individuals.

Finally, in the present study the total increase in profit, calculated as a benefit from lowering the transportation cost, was assigned to producers. Additional studies should be performed to find the benefits to other groups involved in producing, moving and selling products (for example carriers).

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Appendix A

Transportation Zones

Production and market zones used in the present study are taken from the zones used by Jones (1977) in his transportation network (he named it Multi-State Transportation Network). For the purpose of his study he divided the continental USA into 120 zones. Zones in his network are described by nodal cities, counties and BEAs. Basic Economic Areas (BEAs) are economic zones developed by the Office of Business Economics of the Department of Commerce of the USA.

The zones used in the Multi-State Transportation Network were of three types:

1. zones inside the multi-state corridor that are smaller than BEAs; they are presented in Table A-1;
2. zones outside the multi-state corridor the boundaries of which do not follow BEA boundaries; they are presented in Table A-2;
3. zones made up of integral numbers of BEAs; these are listed in Table A-3.

The zones used in the present study and which were taken from Table A-1 are: 30 and 38; those taken from Table A-2 are: 50; those taken from Table A-3 are: 45, 48, 51, 54, 55, 57, 58, 69, 79, 80, 83, 85, 86, 87, 88, 90, 91, 115, 118, 119.

An acronym APDC used in Tables A-1 and A-2 means zones developed by Area Planning and Development Commission of Bureau of State Planning and Community Affairs (formerly called State Planning Bureau) in Georgia (USA).

Table A-1. Corridor Zones.

Zone	Nodal City	APDC	Included Counties
1	Brunswick, GA	—	Liberty, Long, McIntosh, Glynn, Camden CO., GA
2	Jacksonville, FL	APDC 1, FL	Baker, Clay, Duval, Nassau, Putnam, St. Johns
3	Statesboro, GA	Southern	Appling, Bullock, Candler, Evans, Jeff Davis, Tattnall, Toombs, Wayne
4	Waycross, GA	Slash Pine	Atkinson, Bacon, Brantley, Charlton, Clinch, Coffee, Pierce, Ware
5	Dublin, GA	Heart of GA	Bleckley, Dodge, Laurens, Montgomery, Pulaski, Telfair, Treutlen, Wheeler, Wilcox
6	Vasdosta, GA	Coastal Plain	Ben Hill, Berrier, Brooks, Cook, Echols, Irwin, Lanier, Lowndes, Tift, Turner

Table A-1. Corridor Zones (continued).

Zone	Nodal City	APDC	Included Counties
7	Macon, GA	Middle GA	Bibb, Crawford, Houston, Jones, Monroe, Peach, Twiggs
8	Cordele, GA	Middle Flint	Crisp, Dooly Marlon, Macon, Schley, Sumter, Taylor, Webster
9	Albany, GA	S.W. GA	Baker, Calhoun, Colquitt, Decatur, Dougherty, Early, Grady, Lee, Miljer, Mitchell, Semipole, Terrell, Thomas, Worth
10	Lagrange, GA	Chattahoochee -Flint	Carroll, Coweta, Heard, Meriwether, Troup
11	Columbus, GA	Lower Chat- tahoochee Valley APDC 10, AL	Chattahoochee, Clay, Harris, Muscoree, Quitman, Randolph, Stewart, Talbot, GA, Lee, Russell, AL

Table A-1. Corridor Zones (continued).

Zone	Nodal City	APDC	Included Counties
12	Anniston, AL	APDC-4	Calhoun, Chambers, Cherokee, Clay, Cleborne, Cosa, Etowah, Randolph, Talladega, Tallapoosa
13	Montgomery, AL	APDC-9+	Autauga, Dallas, Elmore, Montgomery, Perry
14	Troy, AL	APDC-5	Bullock, Butler, Crenhaw, Lowndes, Macon, Pike
15	Dothan, AL	APDC-7	Barbour, Coffee, Covington, Dade, Geneva, Henry, Houston
16	Decatur, AL	APDC-11	Cullman, Lawrence, Morgan
17	Birmingham, AL	APDC-1	Blount, Chilton, Jefferson, St. Clair, Shelby, Walker
18	Florence, AL	APDC-1	Colbert, Franklin, Lauderdale, Marion, Winston

Table A-1. Corridor Zones (continued).

Zone	Nodal City	APDC	Included Counties
19	Tuscaloosa, AL	APDC-2	Bibb, Greene, Fayette, Hale, Lamar, Pickens, Tuscaloosa
20	Corinth, MS	N.E. MS	Alcorn, Benton, Marshall, Prentice, Tippah, Tishomingo
21	Tupelo, MS	3 Rivers	Calhoun, Chickasaw, Itawanba, Lafayette, Lee, Monroe, Pontotac, Union
22	Columbus, MS	Golden Triangle	Clay, Choctaw, Lowndes, Noxubee, Ortibbeh, Webster
23	Clarksdale, MS	N. Delta	Coahoma, DeSoto, Quitman, Panola, Tate, Tunica
24	Dyersburg, TN	N.W. APDC-	Carroll, Crockett, Dyer, Gibson, Henry, Lake, Obion, Weakly
25	Jackson, TN	S.W. APDC+	Chester, Decatur, Hardeman, Hardin, Haywood, Henderson, McNairy, Madison, Wayne

Table A-1. Corridor Zones (continued).

Zone	Nodal City	APDC	Included Counties
26	Memphis, TN	Memphis Delta	Fayette, Lauderdale, Shelby, Tipton
27	Jonesboro, AK	E.	Clay, Craighead, Crittenden, Cross, Greene, Lawrence, Lee, Ms. Phillips, Poinsett, Randolph, St. Francis
28	Searcy, AK	White River	Cleburne, Fulton, Independence, Izard, Jackson, Sharp, Stone, Van Buren, White, Woodruff
29	Harrison, AK	—	Baxter, Boone, Carroll, Marion, Newton, Searcy
30	Sikeston, MO	Bootheel	Dunklin, Mississipi, New Madrid, Pemiscot, Scott, Stoddard
31	Poplar Bluff, MO	—	Wayne
32	West Plains, MO	S. Central Ozark	Douglas, Howell, Oregon, Ozark, Shannon, Texas, Wright

Table A-1. Corridor Zones (continued).

Zone	Nodal City	APDC	Included Counties
33	Lebanon, MO	Lake of the Ozarks	Camden, Laclede, Miller, Morgan, Pulaski
34	Marshall, MO	MO Valley	Carroll, Chariton, Saline
35	Sedalia, MO	Show-Me	Johnson, Lafayette, Pettis
36	Springfield, MO	Lakes Country	Barry, Christian, Dade, Dallas, Greene, Lawrence, Polk, Stone, Taney, Webster
37	St. Joseph, MO	Bi State	Andrew, Buchanon, Clinton, DeKalb, MO, Doniphan, KS
38	Kansas City, MO	Mid America Reg. Council	Cass, Clay, Jackson, Platte, Ray, MO, Johnson, Leavenworth, Wyandotte, KS
39	Nevada, MO	Kaysinger Basin	Bates, Benton, Cedar, Henry, Hickory, St. Clair, Vernon
40	Joplin, MO	Ozark Gateway	Barton, Jasper, McDonald, Newton

Table A-2. Non BEA External Zones.

Zone	Nodal City	BEA	Included Counties
41	Savannah, GA		Bryan, Chatham, Effingham, Screven, GA; Jasper, SC
43	Milledgeville, GA		Oconee APDC, GA: Baldwin, Hancock, Jasper, Putnam, Washigton, Wilkerson
44	Atlanta, GA	BEA 44 minus:	Oleburne County, AL; Carroll, Coweta County, GA
46	Huntsville, AL		Limestone, Madison, Marshall County, AL; Lincoln, Franklin County, TN
49	Cape Girardeau, MO		Bolinger, Girardeau, MO; Alexander, Hardin, Johnson, Massac, Pope, Pulaski, Union, IL; Ballard, Carlisle, Calloway, Fulton, Graves, Hickman, Livingstone, Lyon, Marshall, McCracken, KY

Table A-2. Non BEA External Zones (continued).

Zone	Nodal City	APDC	Included Counties
50	St. Louis, MO	BEA 114 minus:	Laclede, Pulaski, Reynolds, Texas, MO
52	Columbia, MO	BEA 112 minus:	Putnam, Sullivan, Linn, Chariton, Morgan, Camden, Miller County, MO
53	Chillicothe, MO	BEA 112 minus:	N.W. MO; Green Hills APCD, MO: Atchinson, Caldwell, Daviess, Gentry, Grundy, Harrison, Holt, Linn, Livingston, Mercer, Nodaway, Putnam, Sullivan, Worth

Table A-2. Non BEA External Zones (continued).

Zone	Nodal City	APDC	Included Counties
56	Topeka, KS		Allen, Anderson, Atchison, Bourbon, Brown, Cherokee, Craig, Crawford, Douglas, Franklin, Geary, Jackson, Jefferson, Labette, Linn, Lyon, Marshall, Miami, Montgomery, Nemaha, Neosho, Osage, Ottawa, Pottawatomie, Riley, Shawnee, Wabaunsee, Washington, Wilson, Wooodson, KS
60	Little Rock, AK	BEA 117 minus:	White River APDC, AK (omitted counties are listed in zone 28)
67	Gainesville, FL		Alachua, Bradford, Columbia, Dixie, Gilchrist, Hamilton, Lafayette, Levy, Marion, Sewannee, Union, FL

Table A-3. Zones Comprised of Integral BEAs.

Zone	Nodal City	BEAs
42	Augusta, GA	32
45	Chattanooga, TN	48
47	Nashville, TN	49
48	Evansville, IN	55
51	Quincy, IL	113
54	Des Moines, IN	80, 81, 104, 105, 106
55	Omaha, NE	102, 103, 107, 108
57	Wichita, KS	109, 110
58	Tulsa, OK	119
59	Ft. Smith, OK	118
61	Greenville, MS	134
62	Jackson, MS	135
63	Meridian, MS	136
64	Mobile, AL	137

Table A-3. Zones Comprised of Integral BEAs (continued).

Zone	Nodal City	BEAs
65	Pensacola, FL	39
66	Tallahassee, FL	38
68	Miami, FL	35, 36
69	Boston, MA	1, 2, 3, 4, 5
70	Albany, NY	6, 7
71	Buffalo, NY	8, 9, 10
72	New York, NY	14, 15
73	Scranton, PA	12, 13
74	Harrisburg, PA	11, 16
75	Pittsburgh, PA	66, 67
76	Washington, DC	17, 18
77	Roanoke, VA	19, 20
78	Richmond, VA	21
79	Charlotte, NC	25, 26

Table A-3. Zones Comprised of Integral BEAs (continued).

Zone	Nodal City	BEAs
80	Raleigh, NC	23, 24
81	Greenville, SC	27, 28
82	Columbia, SC	29, 30
83	Knoxville, TN	50
84	Charleston, WV	51, 52, 65
85	Cincinnati, OH	53, 54, 62
86	Dayton, OH	61, 63, 69
87	Cleveland, OH	68
88	Detroit, MI	71, 72, 74
89	Indianapolis, IN	56, 59, 60
90	Chicago, IL	76, 77, 78, 79
91	Milwaukee, WI	82, 83, 84, 85, 86
92	St. Paul, MN	88, 89, 90, 91
93	Billings, MN	94, 95, 100, 101, 150

Table A-3. Zones Comprised of Integral BEAs (continued).

Zone	Nodal City	BEAs
94	Denver, CO	147, 148, 149
95	Oklahoma City, OK	120, 121
96	Texarkana, TX	131
97	Shreveport, LA	132, 133
98	New Orleans, LA	138
99	Tampa, FL	37
100	Amarillo, TX	122, 123
101	Dallas, TX	127, 130
102	El Paso, TX	124, 145, 163
103	Austin, TX	128, 129
104	San Antonio, TX	125, 126, 142, 143, 144
105	Houston, TX	139, 140, 141
106	Salt Lake City, UT	151, 160
107	Phoenix, AR	162

Table A-3. Zones Comprised of Integral BEAs (continued).

Zone	Nodal City	BEAs
108	Albuquerque, NM	146
109	Seattle, WA	153, 154, 155, 156
110	San Francisco, CA	166, 167, 168, 171
111	Los Angeles, CA	161, 164, 165
112	Charleston, SC	31
113	Duluth, MN	87
114	Springfield, IL	57, 58
115	Toledo, OH	70, 75
116	Columbus, OH	65
117	Portland, OR	152, 157, 158, 159, 169, 170
118	Fargo, ND	92, 93, 96, 97, 98, 99
119	Grand Rapids, MI	73
120	Norfolk, VA	22

Appendix B

Description of SIC 249 Commodity Group

The standard Industrial Classification (SIC) is the statistical classification standard underlying all establishment-based economic statistics classified by industry, done by the USA government at the federal level. The SIC is used to enhance the comparability of establishment data describing various aspects of the USA economy. The classification covers the entire field of economic activities and defines industries in accordance with the composition and structure of the USA economy.

The model in this study was tested for the SIC 249 Commodity Group, because complete economic data were available only for this group. Industry group number 249 itself is included in a Major Group 24, which covers all lumber and wood products, except furniture. The SIC 249 Commodity Group consists of three subgroups: SIC 2491, SIC 2493, and SIC 2499.

SIC 2491 — Wood Preserving Products.

These are produced by establishments primarily engaged in treating wood, sawed or planed in other establishments, with creosote or other preservatives used to prevent decay and to protect against fire and insects. This industry also includes the cutting, treating and selling of poles, posts, and piling, but establishments primarily engaged in manufacturing other wood products, which they may also treat with preservatives, are not included.

The wood products included in this category are:

Bridges and trestles, wood: treated

Creosoting of wood

Crossties, treated

Flooring, Wood block: treated

Millwork, treated

Mine props, treated

Mine ties, wood: treated

Piles, foundation and marine construction: treated

Piling, wood: treated

Poles and pole crossarm, treated

Poles, cutting and preserving

Posts wood: treated

Preserving of wood (creosoting)

Railroad cross bridge and switch ties, treated

Railway crossties, wood: treated

Structural lumber and timber, treated

Vehicle lumber, treated

Wood fences: pickets, poling, rails, treated

Wood products, creosoted

SIC 2493 — Reconstituted Wood Products.

These are products made by establishments primarily engaged in manufacturing reconstituted wood products. Important products of this industry are hardboard, particle board, insulation board, medium density fiberboard, waferboard and oriented strandboard.

Detailed products included in this category are:

Board, bagasse

Flakeboard

Hardboard

Insulating siding, board — mitse

Insulation board, cellular fiber or hard pressed (without gypsum) — mitse

Lath, fiber

Medium density fiberboard (MDF)

Particle board

Reconstituted wood panels

Strandboard oriented

Waferboard

Wall tile, fiberboard

Wallboard, wood fiber: cellular fiber or hard pressed — mitse

SIC 2499 — Wood Products, Not Elsewhere Classified.

These are products produced by establishments primarily engaged in manufacturing miscellaneous wood products, not elsewhere classified, and products from rattan, reed, splint, straw, veneer, veneer strips, wicker, and willow.

Details of these products are:

Applicators, wood

Bakers' equipment, wood

Basket except fruit, vegetable, fish, and bait: (e.g., rattan, reed, straw)

Battery separators, wood

Bearings, wood

Beekeeping supplies, wood

Bentwood (steambent) products, except furniture

Blocks, tackle: wood

Blocks, tailors' pressing: wood

Boards, bulletin: wood and cork

Boards: clip, ironing, meat, and pastry — wood

Boot and shoe lasts, regardless of material

Bowls, wood: turned and shaped

Briquettes, sawdust or bagasse: nonpetroleum binder

Bungs: wood

Buoys, cork

Bushings, wood

Cane, chair: woven of reed or rattan

Carpets, cork

Cloth winding reels, wood

Clothes dryers (clothes horses), wood

Clothes drying frames, wood

Clothespins, wood

Clubs, police: wood

Cooling towers, wood or wood and sheet metal combination

Cork products

Corks, bottle

Covers, bottle and demijohn: willow, rattan, and reed

Curtain stretchers, wood

Displays forms for boots and shoes, regardless of material

Dowels, wood

Extension planks, wood

Faucets, wood

Fellies, wood

Fencing, wood: except rough pickets, poles and rails

Firewood and fuel wood containing binders

Flour, wood

Frames: medallion, mirror, photograph, and pictures — wood or metal

Furniture inlays (veneer)

Garment hangers, wood

Gavels, wood

Grain measure, wood: turned and shaped

Hammers, meat: wood

Hampers, laundry: rattan reed, splint, veneer and willow

Handles, wood: turned and shaped

Hubs, wood

Insulating materials, cork

Jacks, ladder: wood

Knobs, wood

Ladder, wood

Last sole patterns, regardless of material

Letters, wood

Life preservers, cork

Mallets, wood

Market baskets, except fruit and vegetable: veneer and splint

Marquetry, wood

Mashers, potato: wood

Masts, wood

Mauls, wood

Mouldings, picture frame: finished

Novelties, wood fiber

Oars, wood

Pads, tables: rattan, reed, and willow

Paints stick, wood

Pencil slats

Plugs, wood

Poles, wood: e.g., clothesline, tent, flag

Pressed logs of sawdust and other wood particles, nonpetroleum binder

Pulleys, wood

Racks, for drying clothes: wood

Rattan ware, except furniture

Reels, cloth winding: wood

Reels, for drying clothes: wood

Reels, plywood

Rollers, wood

Rolling pins, wood

Rules and rulers: wood, except slide

Saddle trees, wood

Sawdust, reground

Scaffolds, wood

Scoops, wood

Seat covers, rattan

Seats, toilet: wood

Shoe stretchers, regardless of materials

Signboards, wood

Skewers, wood

Snow fence

Spars, wood

Spigots, wood

Spokes, wood

Spools, except for textile machinery: wood

Stakes, surveyors': wood

Stepladders, wood

Stoppers, cork

Tile, cork

Tool handles, wood: turned and shaped

Toothpicks, wood

Trays: wood, wicker, and bagasse

Trophy bases, wood

Vats, wood: except coopered

Washboards, wood and part wood

Webbing: cane, reed, and rattan

Willow ware, except furniture

Wood, except furniture: turned and carved

Woodware, kitchen and household

Yardsticks, wood