THE EFFECT OF OUTSOURCING AND SITUATIONAL
CHARACTERISTICS ON PHYSICAL DISTRIBUTION TRANSPORTATION
EFFICIENCY

by

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(ABSTRACT)

This research examined the outsourcing decision for the logistics function of motor
carrier transportation. A full factorial design was executed on a simulated transportation
network to investigate how the efficiency of motor carrier transportation was affected by
how it was structured (private/leased fleet versus contract carrier transportation) and the
characteristics of the transportation activities. Transaction Cost Analysis (TCA) offered a
useful theoretical framework for consideration of this make or buy decision by suggesting
the independent variables of asset specificity, uncertainty, and frequency/volume.

Seven two-part research hypotheses examined the relationships among the
independent variables to gain a greater understanding of the factors which drive the make
versus buy decision for motor carrier transportation.

The major conclusions of this research are:

1)  For the system modelled here, structure (private/leased versus contract
carriers) and volume had the largest effects on transportation efficiency
(mean shipment cost).

2)  The results of this study indicated that there may be important factors within
the nature of the "supplying" industry that impact the make or buy decision.
This research provided strong support for TCA predictions and clearly
demonstrated that TCA is a useful framework for understanding firms' make
or buy decisions. Because of the nature of the transportation industry (the
high level of competition and the lack of a small numbers bargaining situation), the hypotheses in this research clearly indicated that a "buy" rather than a "make" decision was the most efficient alternative; this result is exactly consistent with TCA predictions.

3) For the system modelled here, higher fixed and per mile equipment leasing expenses (incurred in the operation of refrigerated trailers) caused refrigerated shipments to be more expensive than standard dry trailer shipments. That is, asset specificity (in this case, requirements for refrigerated trailer equipment) had a significant effect on shipment efficiency.
ACKNOWLEDGEMENTS

The contributions of a number of people were essential for the completion of this dissertation. The encouragement and enthusiasm of Dr. John T. Mentzer played a significant and meaningful role in the research training that led up to this project, as well as in the dissertation itself. My professional relationship with him has been an important contributor to my development as a researcher; in addition, I also value his friendship.

For their crucial and rigorous insights into several theoretical and methodological issues in this dissertation, I am greatly indebted to both Dr. James R. Brown and Dr. Janet E. Keith. I feel privileged to have had the chance to be associated with researchers of their caliber.

Thanks to Dr. Edward R. Clayton for introducing me to simulation. His enthusiasm and encouragement were important contributors to my understanding of this methodology, as well as to the completion of this project. Dr. Terry R. Rakes graciously consented to serve on the committee, despite an already crowded schedule, and provided crucial guidance in the statistical aspects of simulation modelling.

The Ph.D. program in Marketing at Virginia Tech is supported by a faculty that maintains a philosophy of cherishing fledgling marketing academicians. One of the primary reasons for this environment is Dr. Noreen M. Klein, who served as Chair of the Graduate Programs Committee for the first three years of my doctoral program. Not only did she set an example as an outstanding researcher, but, in addition, her dedication to the program and to each doctoral student was unmistakable. I am fortunate to have been in the doctoral program during her tenure as Chair.

In conclusion, I would like to thank my family. Their patience, support and understanding throughout this program and this dissertation was unwavering. My mother-
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CHAPTER 1

INTRODUCTION

A prevalent trend in business firms over the last decade is the interest in utilizing outside service providers to perform some of a firm’s business functions, i.e., outsourcing (Peters 1991). Davidow and Malone (1992), in The Virtual Corporation argued that the progression of this trend would result in what they termed “the virtual corporation”, where formerly well-defined structures . . . lose their edges . . . [and become] permeable . . . [with] continuously changing interfaces between company, supplier[s], and customers (p. 5-6).

Moreover, Davidow and Malone maintained that this progression toward a virtual corporation is essential for the economic survival of American business.

However, in another view of the outsourcing trend, Peters (1991) warned that decisions about whether to make or buy must be examined carefully for advantages and disadvantages and questioned the wisdom of a widespread predisposition toward “vertical de-integration”.

This research examined the make or buy, i.e., the outsourcing decision for the logistics function of motor carrier transportation of products between manufacturer and customer. According to Bardi and Tracey (1991):

Outsourcing is currently a ‘hot’ topic in the business world, particularly in the area of logistics. . . . The transportation aspect of logistics plays a critical role as the enabler for raw materials and finished goods to move through domestic and world markets. Marketing, manufacturing and other aspects of logistics . . . are greatly impacted by the performance of the transportation function in a company (emphasis added) (p. 15).
Decisions about which business functions will be performed within the boundaries of a firm and which will be performed externally (i.e., make or buy\(^1\) decisions) essentially address how business firms or groups of firms will be organized or structured; that is, what will constitute "a firm," and what the relationships will be between affiliated firms (Coase 1937; Williamson 1971, 1979). Of particular significance within marketing and logistics is the group of firms that comprise a distribution channel. These firms execute the marketing and logistics functions which enable products to proceed from supplier to the production line, as well as from the end of the production line to the intended customer (Stern and Reve 1980). For this reason, the structure of distribution channels, specifically, the degree of integration in a channel, is a fundamental research issue within marketing and logistics (Frazier 1990).

This research used Transaction Cost Analysis as its conceptual foundation. However, it also examined four other frameworks (characteristics of goods, scale economies, functional spin-off, and markets and services) that have been used in marketing to explore the structure of distribution channels. The discussion of these four other frameworks sought to explore potential contributions of these frameworks to the examination of the issue of outsourcing the logistics function of transportation.

\(^1\)Throughout this study, the terms: make or buy; direct or indirect; internal(ize) or external(ize); perform internally or contract/outsource; perform internally or use a third party; private carriage or for hire carriage; and integrated or non-integrated are used synonymously to refer to whether a firm performs a function within the boundaries of the firm or enters into an agreement with another firm to perform the function.
LOGISTICS

According to Williamson, Spitzer, and Bloomberg (1990), there are three well-defined domains that comprise logistics management.

*Materials management* is the logistical relationship between the firm and its suppliers, . . . the inbound side of the logistics process. *Conversion management* is the logistical relationship between the facilities of the firm, . . . the internal component of the logistics process. *Physical distribution management* is the logistical relationship between the firm and its customers, . . . the outbound side of the logistics process (emphasis added) (p. 69).

The three domains of logistics management are supported by five logistics functions: transportation, facility structure, inventory, material handling, and communication/information. The activities that are associated with each of these five functions are depicted in Table 1.

The normative performance implications of the *public versus private* (motor) *carriage decision for outbound transportation* by motor carrier, between manufacturer and customer, were the focus of this study.

**SIGNIFICANCE OF LOGISTICS AND TRANSPORTATION**

In many industries, for each dollar of sales, a firm spends more than $.25 on physical distribution expenses; furthermore, the proportion of corporate asset investments required for physical distribution functions may be 30% or more (Stern and El-Ansary 1988). In fact, in 1989, total logistics expenditures in the US were $577.2 billion, which accounted for 11.1% of the US gross national product. Of these total logistics expenditures, more than one-half (57%) were transportation expenditures, and motor carrier expenses accounted for 77% of the transportation costs (Bardi and Tracey 1991).

In discussing the various logistics functions (see Table 1) and their importance within the logistics system, Williamson, Spitzer, and Bloomberg (1990) maintained that,
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"transportation and warehousing/distribution center management are the traditional core ingredients of the logistics process" (p. 81). Reflecting on the importance of various transportation modes, Delaney (1986) stated that "the engine that drives the performance of the business logistics system is trucking" (p. 35). In 1985, approximately 23% of products transported in the US moved by motor carrier (Stern and El-Ansary 1988).

The details above indicate the economic significance of logistics and transportation. Additionally, it is important to recognize the effect that deregulation has had on the transportation industry. According to Stock (1988):

Within the motor carrier industry . . . the number of firms (private carriers going public as well as new common/contract carriers) have increased dramatically since deregulation (p. 27).

Rakowski, Southern, and Jarrell (1993) provided statistics which supported Stock’s assertion. In 1978, two years prior to the passage of the Motor Carrier Act, there were 16,874 Interstate Commerce Commission (ICC) certified motor carrier firms; in 1989, there were 39,602, a 135% increase. Part of this increase in ICC certified motor carriers was due to the 1978 decision by the ICC to allow private carriers to apply for common or contract carrier operating authority (Mentzer and Krapfel 1981).

The relevance of the effects of the deregulation of the motor carrier industry on this study’s research problem was summarized by Lounesbury (1987).

As we all know, deregulation changed the rules under which the transportation industry operated. Loosened constraints have created a relative free-for-all. The roughly two-thirds of domestic distribution that is still in private carriage . . . is continually being re-evaluated to determine the cost-effectiveness of these operations versus available alternatives (p. 113).

In general, the outcome of deregulation has been an improvement in service, along with a decline in transportation costs (Ballou 1992). Transportation expenses, as a percentage of gross national product, went from 8% to 6.3% in the period 1981 to 1987 (Bardi and Tracey 1991). Rakowski, Southern, and Jarrell (1993) maintained that the
overall effect of deregulation on the motor carrier industry is "a new set of rules . . . [which
has] allowed more competition . . . and operating creativity in the trucking industry" (p.
111).

To summarize the information and discussion presented above:

1) Logistics, particularly transportation, efficiency has substantial economic
implications for the US.

2) There have been significant changes in the transportation industry,
particularly the motor carrier industry, since deregulation, which have
impacted the make or buy decision for transportation service.

3) There exists a substantial degree of interest in the managerial issue of
outsourcing business functions in general, and logistics functions in
particular.

These three points illustrate why the performance implications of the make or buy decision
for motor carrier transportation represents a valuable research issue.

**RESEARCH PROBLEM**

The research problem investigated by this study can be stated: How is the cost of
motor carrier transportation affected by how it is structured (i.e., internally or externally)
and the characteristics of the transportation activities?

**CONCEPTUAL FRAMEWORK**

Transaction Cost Analysis (TCA), which arose from economic and legal literature,
offers a theoretical framework for considering vertical integration issues, i.e., which
functions a firm performs and which functions it contracts with another firm to provide.
Coase (1937) provided the initial explication of TCA’s fundamental philosophy, i.e., that
market transactions are not costless. Williamson (1971, 1975, 1979, 1985) expanded
TCA’s scope by identifying and suggesting operationalizations for transactional dimensions
that influenced the costs of market transacting. The dimensions identified by Williamson include asset specificity, complexity/uncertainty, and frequency. TCA has been used extensively in economics, management, and marketing literature to address the make or buy issue for various business functions. However, perhaps due to the relative lack of hypothesis testing research in logistics, TCA’s potential for investigation of the outsourcing issue in logistics has not been fully exploited.

In addition to TCA, four other theoretical frameworks have been used in marketing research to investigate vertical integration issues within the specific context of channels of distribution. These include: characteristics of goods, scale economies, functional spin-off, and markets and services. As the literature review in CHAPTER II demonstrates, although these other four frameworks are, in general, less comprehensive than TCA for assessing the make or buy issue, a number of factors contained within these frameworks serve to enhance TCA’s conceptualization and the measurement/operationalization of its constructs. Therefore, although TCA provided the underlying conceptual foundation for the present study, factors from the other four frameworks served to augment the conceptualization and facilitate operationalization of asset specificity, complexity/uncertainty, and frequency within the context of this study.

RESEARCH QUESTIONS

This study explored the research problem stated above. In order to accomplish this, the following research questions, suggested by the substantive context of the present study and the conceptual framework outlined above, were examined:

1) Is the relative efficiency of outsourced transportation versus transportation by private fleet affected by the type of carrier equipment required for the transportation activities?
2) Is the relative efficiency of outsourced transportation versus transportation by private fleet affected by operational uncertainty (e.g., delays along transportation routes due to weather, road conditions, or labor unrest)?

3) Is the relative efficiency of outsourced transportation versus transportation by private fleet affected by the volume of products that is transported?

4) What is the combined effect of equipment requirements; operational uncertainty; and volume transported on the relative efficiency of outsourced transportation versus transportation by private fleet?

**RESEARCH METHODOLOGY**

As CHAPTER II demonstrates, empirical research on the outsourcing issue exhibits a lack of uniform results, has been conducted using primarily survey methodology, and requires exploration of the normative performance implications of outsourcing by more adequately addressing the total of: 1) the indirect costs of outsourcing, plus 2) the actual production costs for the business function of interest. This research used an alternative methodology, an experimental design executed on a computer simulation model. The construction of the model, model validation procedures, statistical considerations of simulation, and the experimental design used are described in detail in CHAPTER III. This methodology enabled this study to address some of the vulnerabilities of the survey methodology employed in existing make or buy research through the use of the controlled environment of a simulation model.

**SIGNIFICANCE AND POTENTIAL CONTRIBUTIONS**

The following two sections discuss specific managerial, conceptual, and methodological contributions of this research.
MANAGERIAL SIGNIFICANCE AND CONTRIBUTIONS

Logistics, particularly transportation efficiency, has a substantial impact on the US economy. Moreover, the level of interest in the managerial issue of outsourcing business functions in general, and logistics functions in particular, suggests that the make or buy decision for motor carrier transportation and the performance implications of this decision are issues that have significant managerial relevance.

This research utilized a framework that can be applied to transportation outsourcing decisions. The results of the research generated insight into what factors should be considered in the outsourcing decision, as well as the potential impact of differing levels of those factors on transportation efficiency. In addition, the results of this research may enable third party providers of transportation services (e.g., transport carrier firms) to better target potential customers (firms that are considering outsourcing their transportation activities) by increasing the carrier firms’ understanding of the factors that impact the efficiency of transportation activities when they are performed internally versus when they are outsourced.

CONCEPTUAL AND METHODOLOGICAL SIGNIFICANCE AND CONTRIBUTIONS

CHAPTER II discusses the five frameworks that have been applied to the make or buy issue in marketing and logistics in order to examine their potential for investigation of the present research question. This study operationalized all relevant constructs so that the appropriate interaction effects could be examined. In addition, it investigated normative performance (i.e., efficiency) implications of the make or buy issue.

The computer simulation and experimental design methodology, by providing a controlled environment, facilitated the examination of the total cost implications of transportation outsourcing decisions.
The majority of logistics research has failed to utilize hypothesis testing, neglected reliability and validity appraisals, and used analytical techniques that are somewhat less than rigorous (Mentzer and Kahn 1993). This research employed a hypothesis testing approach by utilizing a conceptual framework that is relevant to the substantive logistics issue of the outsourcing of transportation activities to examine this logistics research problem.

**POTENTIAL LIMITATIONS**

As does all research, the study possesses limitations. The primary source of the limitations of this research is the fact that it utilized a computer simulation model.

**LIMITATIONS OF COMPUTER SIMULATION MODELLING**

The first limitation to be considered is a problem that consistently arises with the use of simulation models, that of model validity, i.e., whether the model is a reasonable representation of the system being investigated. A further complicating factor is that even if techniques used for model validation demonstrate some degree of confirmation of the model’s representativeness with regard to the system being investigated, that representativeness cannot be assumed for the full range of system conditions.

A second limitation of computer modelling is that even if some degree of confirmation of the model’s representativeness of the system under investigation is demonstrated, the simulation model constructed for this study was obviously restricted as far as its depiction of transportation situations faced by all firms. This restriction limits the generalizability of the research results to the type of situation epitomized by the model.

Finally, the third limitation pertains to the analysis of the data generated by a simulation model. Statistical techniques used for the model’s data analysis make a number of assumptions about the nature of the sample data. These assumptions customarily pertain
to the independence of the data samples, the normality of the populations from which data samples originate, and the equality of the population variances. Probably the most pertinent of these three assumptions when using simulated data is the independence assumption, since samples obtained during subintervals of a simulation run are autocorrelated (Fishman and Kiviat 1968). Violation of these assumptions can result in a loss of power, i.e., diminish the ability to detect significant population differences.

The three limitations of computer simulation modelling outlined above will be discussed below in light of the objectives and contributions of this research.

Pritsker (1986), the author of the simulation language and software used to construct the model in this research, maintained that modelling systems is fundamentally an art.

The scope of . . . every model of a system is determined solely by its reason for being identified and isolated. The scope of every simulation model is determined by the particular problems the model is designed to solve (p. 2).

The process of model construction and validation is essentially a trade-off between realism and simplicity. The essence of the system must be abstracted, but the level of detail must not overwhelm the purpose for which the model is constructed. The factors represented and the level of detail for the transportation system model constructed for this research were guided by: 1) the theoretical framework chosen for the investigation of the research problem, and 2) the level of detail necessary for the investigation of the specific research questions. The results of validation procedures provided an estimate of how well the model conformed to the system it represented. Details of the model's construction and validation procedures are presented in CHAPTER III.

Although the simulation model constructed for this research cannot be representative of all transportation systems, generalizability was not the principal goal of this research. According to McGrath and Brinberg (1983), "all [research] methods are
flawed, but different methods are flawed differently" (p. 116). The goal of this study was to use a research method that addressed some of the drawbacks of the existing research on the make or buy issue. Previous research utilizing TCA has been conducted using descriptive methodology, primarily surveys. While this methodology is capable (through representative sampling techniques) of a high degree of generalizability, it is restricted with regard to: 1) realism of context (for the objects in the system of interest) and 2) precision in control/measurement/manipulation of variables (McGrath 1982). The methodology used in this research, an experimental design conducted on a simulated system, more adequately addressed the restrictions of descriptive methodology, since it was capable of realism of context and precision in control/measurement/manipulation of variables. This issue is discussed in more detail in both CHAPTERS II and III.

The statistical assumptions of analysis of variance, which was used to analyze the data generated by the transportation simulation model, were outlined above, and include: independence of samples, normality of population distributions, and homogeneity of population variances. Independence of samples for the simulation data in this research was maintained by the use of independent simulation replications (independent generation of random number streams among samples and across cell treatments). This is in contrast to collecting observations on subintervals of simulation runs, a sampling technique which introduces autocorrelation into sample data. Regarding the normality and equal variance assumptions, Scheffe maintained that, if each cell contains an equal sample size, the F-test used in analysis of variance is relatively insensitive to departures from normality and homogeneity of variance. The research design (described in detail in CHAPTER III) maintained an equal number of simulation runs (replications) for each cell in the experimental design.
FURTHER LIMITATIONS

In addition to the limitations inherent in simulation modelling methodology, this section considers some further limitations of the present research, which are the result of the limitations in scope necessary to render any single research project doable. These limitations can generally be addressed by further research.

This research only investigated the logistics function of transportation. Furthermore, only the outbound side of the transportation function was represented, and only one transportation mode, transportation by motor carrier, was represented. Finally, the model constructed for this research was relatively unsophisticated in that it only considered two echelons of a distribution system (manufacturer and customer), instead of three or more (e.g., manufacturer, warehouse/distributor, customer).

Decisions about one logistics function must be examined in consideration of how they affect the logistics system as a whole. For this reason, such issues as inbound transportation and alternative transportation modes; other logistics functions (e.g., materials handling, facility structure, communication/information, and inventory); and multiple echelons of the system are important when evaluating the efficiency of a logistics system. These issues should be addressed in future research.

ORGANIZATION OF THE DISSERTATION

This chapter provided an overview of the present study. Substantive justification for the study was presented; the research problem was introduced; research questions were delineated; the conceptual foundation for the study was presented; the research methodology was discussed; and the significance, contributions, and limitations of the research were considered.
CHAPTER II reviews economics, management, marketing, and logistics literature that has dealt with the present research problem. An appraisal of this literature provides the rationale for the conceptual framework chosen for this research, as well as establishing the contribution made by this study.

CHAPTER III discusses previous applications of computer simulation methodology in economic and logistics research, develops the research hypotheses, and describes the methodology that was used to test the hypotheses. CHAPTER IV describes the testing and operationalization of the simulation model and the results of the statistical analyses. CHAPTER V presents conclusions and implications of the results of the hypotheses tests, discusses the study's limitations, and considers suggestions for future research.
CHAPTER II

LITERATURE REVIEW

This chapter contains a review of the literature relevant to firms’ make or buy decisions. The next section identifies five conceptual frameworks from marketing literature that have been used to explain the structure of distribution channels. Sections three through six examine conceptual and empirical literature relevant to the five frameworks. Section seven integrates the five frameworks and presents the conceptual basis for the present study. Section eight discusses logistics literature in general and transportation literature in particular with regard to the make or buy decision. The final section demonstrates the significance of the present study in light of the existing knowledge of the research problem presented in this literature review.

DISTRIBUTION CHANNEL STRUCTURE

In proposing the political economy framework for research on channels of distribution, Stern and Reve (1980) stated that the primary purpose of channels of distribution was an economic one, that of "bridging the gap between production and consumption" (p. 55). Stern and Reve subdivided the internal economy of distribution channels into two domains: economic structure and economic process. The economic structure refers primarily to the "vertical economic arrangements or the transactional form of the channel" (p. 55), while the economic process refers to decision policies in the channel.

In discussing the economic structure of channels of distribution, Frazier (1990) maintained that:

Several different types of flows will exist between members of a [distribution] channel. These flows can involve (1) the physical product or service, (2) title to the product or service, (3) payment for the product or service, and (4) information concerning the product or service, customers, competitors, and channel
policies. In order to facilitate these flows within the channel, a number of functions (e.g., transportation) . . . must be undertaken by channel members.

In "direct" [integrated] channels, firms primarily use their own personnel (e.g., salespeople, engineers) and physical assets (e.g., delivery vehicles, warehouses) to perform necessary channel functions. On the other hand, firms relying on indirect [non-integrated] channels use independent organizations (emphasis added) (p. 259).

Five conceptual frameworks have been used in marketing literature to explain the occurrence and performance of alternative channel structures with regard to the degree of vertical integration (Frazier 1990; Frazier, Sawhney, and Shervani 1990). The first is the characteristics of goods framework by Aspinwall (1958, 1962). The second and third are closely related and are known, respectively, as the scale economies (Stigler 1951; Mallen 1973; Williamson 1975, 1985) and functional spin-off (Mallen 1973) frameworks. The fourth framework is the markets and services framework (Bucklin 1966), and the fifth is transaction cost analysis (TCA) (Coase 1937, 1988a, 1988b, 1988c; Williamson 1971, 1975, 1979, 1981a, 1981b, 1985, 1988, 1991). The predictions made by each of these frameworks regarding: 1) channel structure, i.e., integration, and 2) the performance implications of differing channel structures, are frequently contradictory. In addition, at least two of the approaches (characteristics of goods and scale economies) appear to ignore a number of important factors that impact channel structure and performance. Commenting on channel structure research, Frazier (1990) stated:

The most urgent need . . . at this time appears to be the development of integrative theoretical models . . . . A starting point would be to draw together some of the key constructs embedded in the characteristics of goods, markets and services, functional spin-off, transaction cost analysis, and scale economies frameworks (p. 268).

The next four sections of this chapter discuss the five theoretical frameworks employed in marketing to address the make or buy decision. This discussion will provide the basis for the conceptual framework used in this research.
CHARACTERISTICS OF GOODS

Conceptual Research

Aspinwall (1958, 1962) proposed five characteristics of goods (products) that influence the structure of channels of distribution:

1) Amount of time consumers spend searching prior to purchase of a product.
2) Replacement rate or frequency of purchase.
3) Time required to consume a product.
4) Adjustment or service needed to meet customer needs; i.e., product complexity.
5) Gross margin (difference between selling price and cost of goods sold).

According to this framework, integrated or direct channels are best for products that: 1) consumers are willing to spend time searching for, 2) are purchased infrequently, 3) require a relatively long time to consume, 4) require substantial adjustment or service to meet customer needs, and 5) can command a high gross margin. Because consumers purchase these products relatively infrequently and are willing to search for them, a firm can maintain fewer purchase outlets; the high gross margins these products command will offset the high fixed investments required for integrated channels. Finally, integrated channels are desirable because they allow a firm to maintain a relatively high degree of control over these complex products, which require adjustment or service.

On the other hand, non-integrated (indirect) channels are indicated for products that: 1) consumers are not willing to spend time searching for, 2) are purchased frequently, 3) require a relatively short time to consume, 4) require relatively little adjustment or service to meet customer needs, and 5) command lower gross margins. Because consumers purchase these products frequently and do not feel the need to spend time searching for them, a firm must maintain more purchase outlets. The lower gross margins for these products will not
be sufficient to offset the high fixed investments that would be required for integrated channels. Finally, since these goods require little in the way of adjustment or service, the lower degree of control afforded by non-integrated channels should be sufficient (Aspinwall 1958, 1962; Frazier 1990; Frazier, Sawhney, and Shervani 1990).

**Empirical Research**

Empirical support has been provided for three of Aspinwall’s characteristics of goods predictions (2, 4, and 5). Lilien (1979), using a database developed from questionnaires completed by 125 firms, developed and estimated a linear model describing distribution channel structure decisions. He found that direct channels tend to be used for products in the early stages of their life cycles. Under the assumption that gross margins tend to be relatively high during the early stages of a product’s life cycle (at least for a skimming pricing strategy), Lilien’s findings can be taken as confirmation of Aspinwall’s high gross margin-direct channel correlation. Lilien also found that when purchase of a product required extensive analysis and the product was purchased infrequently, direct channels tended to be the rule. This last finding was also confirmed by Anderson (1985), Anderson and Coughlan (1987) and Coughlan (1985), who found that differentiated and/or custom made products tend to be distributed through direct channels.

**Summary of Characteristic of Goods Framework**

Although the five characteristics of goods proposed by Aspinwall are intuitively appealing, this framework appears to lack a "strong theoretical theme" (Frazier 1990, p. 264). Related to this lack of a theme are two issues: 1) several of the characteristics appear to be virtually identical or at least very closely related, and 2) the framework appears to be somewhat limited in scope. An illustration of the first issue is the fact that the
products will not be sufficient to offset the high fixed investments that would be required for integrated channels. Finally, since these goods require little in the way of adjustment or service, the lower degree of control afforded by non-integrated channels should be sufficient (Aspinwall 1958, 1962; Frazier 1990; Frazier, Sawhney, and Shervani 1990).

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replacement rate or frequency of purchase for a product is certainly correlated, if not identical, to the time required to consume a product. The second issue is illustrated by the fact that the framework appears to focus on end use consumers and products, rather than industrial customers and products.

SCALE ECONOMIES AND FUNCTIONAL SPIN-OFF

Conceptual Research

Scale economies refer to whether the average cost per unit of production decreases with increasing production volume. When a firm’s production occurs in the portion of the total cost curve that is negatively sloped, the average cost of production decreases as the total production volume increases. Because the fixed costs incurred remain constant, they can be distributed over a larger volume of units produced, which lowers the average cost for each unit of production (Talley 1988; Frazier 1990).

The scale economies approach to the channel structure issue focuses primarily on the size of a firm, with the assumption that firm size is positively correlated with distribution volumes, and the attendant distribution costs. Under the scale economies framework, a positive relationship exists between channel volume and degree of integration. The reason for this relationship is that if channel volume for a product line is low, channel intermediaries can aggregate product lines from various manufacturers in order to realize scale economies. However, if channel volume for a product line is high, a more integrated channel is preferred, since distribution costs can be spread over the larger volume to yield lower average costs (Frazier 1990; Frazier, Sawhney, and Shervani 1990; Mallen 1973).

Williamson (1975, 1985) addressed the scale economies issue within his TCA framework, emphasizing that firms will seek to minimize the total of transaction and production (or distribution) costs. Scale economies refer primarily to the production (or
distribution) cost portion of a firm's total costs. According to Williamson, "The firm is simply better able to realize economies of scale as its own requirements become larger in relation to the size of the market" (1985, p.94).

Another point of view concerning the scale economies approach comes from Stigler (1951). Stigler viewed firms' total cost curves as being composed of various functional cost curves. Furthermore, he proposed that the degree of integration in an industry was a function of the maturity of the industry and the extent of the market. Applying Adam Smith's theorem that "the division of labor is limited by the extent of the market" (p.185) to the issue of vertical integration, Stigler maintained that firms in relatively immature industries would perform more functions internally, since few firms specializing in intermediate functions would exist in an immature market (i.e., there tends to be less "division of labor" within the industry). As the industry matures, subsidiary firms arise that are willing to undertake specialized functions, and firms in the industry become less vertically integrated as they turn over some functions to these subsidiary firms. Finally, when the industry declines, these subsidiary firms also decline, forcing firms in the industry to re-integrate and perform more of the intermediate functions themselves.

Using Stigler's article as a foundation, Mallen (1973) developed the functional spin-off framework. Mallen maintained that:

given a specific level of demand, firms will try to maximize profits by designing or selecting a channel which will generate the lowest total average costs for their organizations (p. 19).

Keeping in mind Stigler's proposal that firms' total cost curves are made up of the total cost curves of the various functions performed, assume that the total cost curve for a distribution function is negatively sloped. Suppose a firm producing a small volume is faced with the choice of performing a distribution function internally or outsourcing the performance of the function. Since the cost curve for the function is negatively sloped
(indicating that economies of scale are possible), it may be more economical for the firm to "spin-off" the function to a marketing intermediary, who can combine the volumes of several small producers in order to realize economies of scale in the performance of the function. On the other hand, a firm producing large volumes would have no reason to spin off the function because they are themselves able to realize scale economies. Mallen qualified his predictions by pointing out that in new or declining industries or markets, there may be few intermediaries because low industry volume precludes their profitability.

Empirical Research

Although no empirical research has explicitly used the functional spin-off framework, a number of studies have incorporated the scale economies framework.

Lilien’s (1979) analysis of the database mentioned above found that firms manufacturing products whose average order size was large (presumably indicating a high channel volume) used integrated channels. Lilien’s results also indicated that direct channels predominated for products in the early stages of their life cycles, supporting Stigler’s premise concerning immature industries.

Levy (1981, 1985), using data on 69 manufacturing firms from Standard and Poor’s Compustat tapes, hypothesized and found a negative relationship between firm size and degree of integration. This relationship might be explained by dis-economies of scale in manufacturing, i.e., a rising functional total cost curve motivating firms to externalize, rather than internalize a function.

Walker and Weber (1984) examined data on one manufacturer’s make or buy decisions for automobile component parts and found that differences in average production costs were the strongest predictor of firms’ integration decisions. As discussed above, an important determinant of production costs is the shape of the total cost curve, i.e., the
presence or absence of economies of scale; therefore Walker and Weber’s results tend to support the scale economies framework.

John and Weitz (1988) surveyed a sample of 87 industrial firms and found mixed support for the predictions of the scale economies framework. Sales territories which were less densely populated with a firm’s customers tended to be characterized by less integrated channels of distribution. Assuming that the less dense customer concentrations were correlated with smaller channel volumes, these smaller volumes may have prompted firms to spin-off channel functions to intermediary firms, who could combine volumes from several producers and realize scale economies.

Klein (1989) and Klein et al. (1990) surveyed Canadian export firms to investigate the level of integration in international markets. Their results supported the scale economies/functional spin-off framework predictions by demonstrating that integrated channels were the rule when product sales volume was high.

Anderson (1982) and Anderson and Schmittlein (1984), in an investigation of firms’ propensity to use direct versus indirect sales forces, measured channel volume by estimating the size of firms in the study. If firm size is assumed to be indicative of channel volume, these results indicated a positive relationship between channel volume and the firm’s use of a direct sales force, a finding which supports the predictions of the scale economies/functional spin-off framework.

**Summary of Scale Economies and Functional Spin-Off Frameworks**

These two frameworks address essentially the same issue, i.e., production costs. Although there is a fair amount of empirical support for this issue with regard to distribution costs and channel structure, there exists within these frameworks "the bias in favor of production cost determinism" (Day and Klein 1987, p. 46) that characterizes the majority of
economics literature. This bias ignores the transaction cost aspect of agreements and relationships among firms in a distribution channel.

MARKETS AND SERVICES

Conceptual Research

Bucklin (1966) maintained that the structure of distribution channels arose in response to competitive pressures. Additionally, he contended that specialization of labor within a channel had the goal of accomplishing the channel functions at the lowest cost. Bucklin identified three market and services factors that were hypothesized to affect the costs involved in channel functions:

1) Number and size of the firm’s customers
2) Geographical dispersion/location of the firm’s customers
3) Customer service requirements, such as delivery time, order size, and availability of products

According to Bucklin, direct channels are more efficient when a firm faces a few large customers who are concentrated geographically and demand only moderate levels of customer service, since the investments involved in serving these customers are more likely to be recovered. However, if a firm’s customers include many small, geographically dispersed customers, who demand high levels of customer service, indirect channels are more efficient, since the cost to the firm of providing the service levels demanded to each of these small customers would be prohibitive (Bucklin 1966; Frazier 1990; Frazier, Sawhney, and Shervani 1990).
**Empirical Research**

Although there are no empirical studies that explicitly tested Bucklin’s predictions, the results of both Lilien (1979) and Anderson (1985) supported the customer service requirement factor mentioned by Bucklin. Lilien found that requirements for a high level of technical service were associated with direct channels, while Anderson found that when the importance of non-selling activities was high, "e.g., . . . service from the salesperson after the sale" (1985, p. 246), direct sales forces tended to be the rule.

**Summary of Markets and Services Framework**

Two points regarding this framework are noteworthy. One is its emphasis on customer demands, and the other is the consideration that the framework gives to the role of logistics (physical distribution) functions in channel integration decisions (Frazier, Sawyer, and Shervani 1990).

**TRANSACTION COST ANALYSIS**

**Conceptual Research**

The primary contributors to the conceptual foundation of the TCA framework are Ronald Coase (1937), George Stigler (1951), Herbert Simon (1957), Kenneth Arrow (1961), and Oliver Williamson (1971, 1975, 1979, 1981a, 1981b, 1985, 1988, 1991), but elements of this conceptual framework can be seen in earlier economic writings.

As early as 1927, Lavington, in comments based on Marshall’s Industry and Trade, commented on "certain technical conditions which partially neutralize the effect . . . of the main forces working for the vertical dissolution of processas" (p. 27). Lavington’s discussion of the "technical conditions" is remarkably similar to Williamson’s (1975) explication of asset specificity and uncertainty.
Jewkes (1930) discussed

[the distinction] between its [integration's] advantages on the one side, during periods of relative stability and free competition and, on the other, when monopoly influences are at work (emphasis added) (p. 622).

In addition, Jewkes alluded to

the diverse ways in which integration reacts to differences in the nature of the surrounding economy (p. 638).

Echoes of Jewkes' contrast between free competition and monopoly can be recognized in Williamson's (1975) discussion of small numbers bargaining when specific assets are involved, while the firm's reaction to the "nature of the surrounding economy," referred to by Jewkes, is reflected in Williamson's interpretation of levels of integration and uncertainty.

Coase. Coase's "The Nature of the Firm" (1937) attempted to deal with deficiencies in classic economic theory and discover why firms exist. His primary contribution was an examination and critique of a fundamental assumption of classical economic theory, i.e., that the price mechanism for regulating markets is costless. Coase maintained that firms exist because information is, in fact, imperfect and costly; that is, markets are characterized by information asymmetries and exchange costs. In Coase's words:

the operation of a market costs something and by forming an organization [the firm] and allowing some authority . . . to direct the resources, certain . . . costs are saved (p.338).

In a later description of transaction costs Coase (1988b) wrote:

There are a vast number of possible contractual arrangements [i.e., negotiations and affiliations] but, absent firms, . . . a great part of the available resources would be absorbed in making the arrangements for the contracts needed to bring about these transactions and in providing the information on the basis of which decisions would be made (p. 38).

Stigler. The fundamental premise of George Stigler's (1951) article "The Division of Labor is Limited by the Extent of the Market" (as discussed above under SCALE
ECONOMIES AND FUNCTIONAL SPIN-OFF: is that the level of integration depends on the maturity of the industry or market. According to Stigler’s predictions, firms in both new and declining markets tend to be vertically integrated because the market is not developed enough to support the existence of functional intermediaries or specialists, while firms in mature, vital markets are less integrated because these markets can support the existence of functional specialists that can profitably perform intermediate tasks.

Stigler’s primary contribution to TCA can be seen in Williamson’s explication of the transaction dimension of asset specificity. As discussed below (see Williamson), the central theme of the asset specificity dimension is the concept of small numbers bargaining, with the concomitant increase in transaction costs. The fact that only small numbers of intermediaries or specialists are present in an industry or market is a direct result of Adam Smith’s theorem that the "division of labor [specialization] is limited by the extent of the market" (Stigler 1951, p. 185).

Simon. Herbert Simon’s (1957) contribution to TCA derives from his clarification of bounded rationality, which appears as one of two important behavioral assumptions in the TCA framework. Decision makers are said to exhibit bounded rationality because, although they may intend to make rational decisions, this rationality is restricted by the fact that acquisition of information on all possible alternatives is limited and costly.

Arrow. Kenneth Arrow (1969) submitted testimony to the Congressional Joint Economic Committee that attempted to explain market failure, i.e., to clarify the conditions under which the "price system is an efficient resource allocating mechanism . . . [as well as] when it fails to function" (p.47). Arrow pointed out that under certain conditions, transaction costs interfere with market (price) allocation of resources. He defined transaction costs as the "costs of running the economic system" (p. 48), i.e., the "costs of bargaining, assembling information, monitoring compliance with agreements" (John 1984,
p. 279) and suggested that vertical integration occurs when the costs of intrafirm "buying and selling" are lower than the costs of buying and selling on the market.

Arrow's contributions to TCA are derived primarily from his discussions of: 1) uncertainty "as to which of several states of the world will obtain" (p. 54), 2) information asymmetries, 3) appropriability of commodities, and 4) small numbers of buyers and sellers. These themes can be seen in Williamson's (1975, 1985) arguments regarding: 1) uncertainty, 2) opportunism, 3) asset specificity, and 4) small numbers bargaining.

Williamson. Despite the fact that Coase, Stigler, Simon, and Arrow made significant conceptual contributions to the development of the TCA framework, Oliver Williamson is generally acknowledged to be responsible for developing TCA sufficiently to permit hypothesis testing. Although portions of Williamson's framework have implications for antitrust issues, labor relations, and organizational forms (1975, 1985), the relevant portions of the TCA framework for the present study concern: 1) the behavioral assumptions and 2) the dimensionalizing of transactions.

In his description of the behavioral assumptions of the TCA framework, Williamson asserted that

transaction cost analysis characterizes human nature as we know it by reference to bounded rationality and opportunism. The first acknowledges limits on cognitive competence. The second substitutes subtle for simple self interest seeking (emphasis added) (1985, p. 44).

Bounded rationality is a "semistrong form of rationality" (Williamson 1985, p. 45) that acknowledges human limits on rational decision making abilities. Referencing Arrow's discussion of information asymmetries and market failure, bounded rationality can be thought of as a consequence of the cost of acquiring information. Under the assumption of bounded rationality, transaction costs, which are the costs of "planning, adapting, and
monitoring transactions" (Williamson 1985, p. 46), assume increased significance in the issue of structuring economic activities.

Williamson (1988) maintained that opportunism requires economic activity to be organized so that parties who voluntarily carry out the terms of an agreement (contract) will not be injured by parties who fail to adhere to the contract. Table 2 summarizes the governance/economic structure implications of the behavioral assumptions of TCA.

The TCA framework examines the extent of firm boundaries, i.e., which functions are organized internally versus externally, by scrutinizing the transaction(s) that must occur in order to perform a function. The framework considers the range of methods for governing transactions, a range which extends from governance by the price mechanism of markets, through increasingly elaborate contracts between two firms, to the internal hierarchical governance (by fiat) that occurs within an organization (Williamson 1975, 1979).

The normative performance implications of the TCA framework addresses the goal of economizing on the sum of transaction and production costs, not to the consideration of one to the exclusion of the other (Day and Klein 1987). Indeed, Williamson made the point that:

whether transaction cost economies are realized at the expense of scale economies or scope economies . . . needs to be assessed. A tradeoff framework is needed to examine the production cost and governance [transaction] cost ramifications of alternative modes of organization simultaneously (1985, p. 61).
The second of Williamson’s two primary contributions lies in the dimensionalization of transactions according to certain critical characteristics. This dimensionalization accomplished three objectives: 1) transactions can be categorized according to critical dimensions or characteristics, 2) the categories can be matched with different economic structures, and 3) normative performance implications can be derived using the transaction categorizations and the behavioral assumptions of TCA. These three objectives enabled the constructs of the framework to be operationalized, making hypothesis testing possible.

The three dimensions Williamson used to characterize transactions included: 1) the extent to which transaction specific assets are required or asset specificity, 2) the degree of uncertainty/complexity surrounding the transaction, and 3) the frequency of transaction occurrence (1971, 1975, 1981a). Requirements for specific assets can take four forms: site specificity, physical asset specificity, human asset specificity (“learning by doing” (1981a, p. 555)), and dedicated asset specificity.

Site specificity refers to the location of successive stages of production (or distribution) in proximity so as to decrease production costs (e.g., inventory, transportation). These assets are generally immobile, making relocation costly. Physical asset specificity refers to the requirement of specialized production (distribution) equipment. Human asset specificity refers to specialized knowledge or experience that is gained by the performance of a job task or function. Finally, an example of dedicated assets might involve the expansion of plant capacity in order to accommodate the needs of a particular buyer (Williamson 1985).

The significance of the asset specificity dimension for transaction costs lies in the fact that both parties (the "buyer" and the "seller") are bound together to some degree. The buyer is bound because the specificity of the assets required precludes there being large numbers of sellers; the seller is bound because the specificity of the assets required
precludes there being alternative uses (and therefore buyers) for the assets. The behavioral assumption of opportunism introduces the possibility that the seller will "hold up" the buyer. That is, knowing that the buyer has few or no alternative suppliers (other sellers) of the assets, the seller will demand exorbitant fees for the use of the specialized assets (Williamson 1981a). Williamson states:

where asset specificity is great, buyer and seller will make special efforts to design an exchange relationship that has good continuity properties (1981b, p. 1546).

Williamson maintained that efforts to provide "good continuity properties" may include internal organization of transactions if the degree of asset specificity is great enough.

Williamson refers to the second transaction dimension as complexity/uncertainty in his earlier writings (1971, 1975), while later work (1985, 1981a, 1981b, 1988, 1991) refers to the dimension simply as uncertainty. This dimension is critical to categorizing transactions due to the two behavioral assumptions of bounded rationality and opportunism. Conditions of uncertainty may affect buyers and sellers differently, so that the boundaries imposed on the rationality of decision makers may result in information asymmetries. These information asymmetries introduce the chance for parties on either side of the transaction to take advantage of the other party's relative lack of relevant information, i.e., to behave opportunistically (Williamson 1971, 1975). In this case:

internal organization [vertical integration] often has attractive properties in that it permits the parties to deal with uncertainty/complexity in an adaptive, sequential fashion without incurring the same types of opportunism hazards that market contracting would pose. Such adaptive, sequential decision processes economize greatly on bounded rationality [see Table 2]. Rather than specifying the decision tree exhaustively in advance, and deriving the corresponding [contingencies]. . . , events are permitted to unfold and attention is restricted to only the actual rather than all possible outcomes (emphasis added) (Williamson 1975, p. 25).

Williamson's (1985) rationale regarding this dimension reveals that the uncertainty that is of concern is uncertainty prompts an increasing number of contingencies to be considered when attempting to forge and administer agreements (i.e., contracts) between
two parties for the performance of a function. As the number of contingencies increases, it becomes progressively more difficult to construct, monitor, and enforce existing agreements or contracts. Uncertainty that has this effect varies according to the context of the function of interest, but examples include: 1) unpredictability in either availability or price of manufacturing inputs or, especially in a transportation context, 2) events that cause unpredictability in the activities (i.e., pickup/delivery and/or transportation) surrounding the movement of goods (Bardi and Tracey 1991). Examples might include weather conditions, labor unrest, or road repairs that cause delays along transportation routes.

One of the aspects of monitoring contracts or agreements that Williamson (1981a) specifically considered was related to what Alchian and Demsetz (1972) termed the problem of "metering input production and . . . rewards" (p. 778). This problem is especially significant when the tasks required for performing a function are complex and/or there is increased uncertainty surrounding the function. Examples of this in a transportation context might be: 1) the occurrence of complex requirements for loading/unloading of a particular type of product, or 2) delays in line haul or pickup/delivery times because of road or weather conditions. Williamson maintained that this aspect of monitoring human productivity is the "internal . . . counterpart for uncertainty" (1981a, p. 564).

It is worth noting here that the construct of uncertainty as well as its relationship to organizational structure has been dealt with extensively in organizational, strategic management, and public policy research. However, the definition and, consequently, the operationalization of uncertainty in this research has varied rather widely (Noordewier, John, and Nevin 1990).

For example, Lawrence and Lorsch (1967), Hayes and Abernathy (1980), Porter (1980), and Harrigan (1983) all maintained that there are inherent dangers in vertical integration in industries characterized by instability (e.g., volatility, uncertainty). The
rationale for the hazards inherent in vertical integration includes the necessity for strategic flexibility in a volatile environment, as illustrated, for example, by the financial danger of investment in assets which might become technically obsolete.

Duncan (1972), in research that developed a scale measuring perceived uncertainty, maintained that uncertainty consisted of three components: 1) lack of information regarding relevant environmental factors, 2) lack of information regarding organizational outcomes, and 3) lack of ability to assign probabilities to decision outcomes. Duncan proposed two dimensions, simple-complex and static-dynamic, that contributed to perceptions of environmental uncertainty. The simple-complex dimension deals with the number of decision factors in the environment, while the static-dynamic dimension considers how much decision factors change over time. Duncan’s results indicated that environments characterized as complex-dynamic resulted in the greatest amount of perceived uncertainty. Since the primary goal of Duncan’s research was to develop a measure of perceived uncertainty, there were no predictions concerning organizational structure under various degrees of uncertainty.

Pfeffer and Salancik (1978) viewed uncertainty as being the result of: 1) environmental characteristics (e.g., industry concentration, availability of scarce resources, nature and extent of linkages among organizations) and 2) the relationships among organizations in an industry (e.g., degree of conflict and interdependence among organizations) and proposed that vertical mergers were prompted by a desire to reduce problematic resource interdependence. An analysis of 854 mergers revealed that "resource interdependence accounted for 49.2 percent of merger activity" (p. 118), that is, firms tended to merge with firms they sold to and/or firms they purchased from.

Schoonhoven (1981), defining technological uncertainty as task (workflow) uncertainty, investigated the interaction of organizational structure and technological
uncertainty on organizational effectiveness. However, organizational structure in this study consisted of *intra*-organizational structure (e.g., destandardization, decentralization, and professionalization), not the characteristics of linkages between organizations. Leblebici and Salancik (1981) discussed what they termed two components of uncertainty, *volatility* and *diversity*. Volatility was defined as the "rate of change among [an organization’s environmental] activities", while diversity was defined as "the range of an organization’s environmental activities" (p. 578). Although their research, like Schoonhoven’s, dealt primarily with intra-organizational structure, their argument that an uncertain environment required flexibility could have implications for inter-organizational structure.

The primary goal of Dess and Beard’s (1984) research was to establish construct validity and reliability for the dimensions describing organizational environments. They described three environmental dimensions: *munificence, dynamism, and complexity*. They defined dynamism as "change that is hard to predict" (p. 56), and suggested that long term contracts and vertical integration were strategies used to create a more predictable environment. Environmental complexity was defined as being characterized by heterogeneous activities (e.g., requirements for multiple manufacturing inputs and/or the production of multiple products). Dess and Beard contended that complexity increased information processing requirements and perceptions of uncertainty, but offered no predictions regarding complexity’s effect on inter-organizational linkages.

Balakrishnan and Wernerfelt (1986) asserted that since specialized assets, by definition, have low salvage value, investment in these assets (i.e., vertical integration) in an environment characterized by technological uncertainty would be less than desirable. This is because "as the likelihood of obsolescence goes up, the expected profitability of the investment goes down" (p. 348). According to Balakrishnan and Wernerfelt, the contradiction between this prediction and Williamson’s uncertainty hypothesis is explained
by that fact that technological uncertainty "does not increase the number of contingencies in a hypothetical contract with an independent supplier, it only makes the single contingency [technical obsolescence] more likely" (p. 348). In other words, technological uncertainty does nothing to increase transaction costs.

Finally, Venkatraman (1989) attempted to more precisely define the concept of fit (e.g., fit between degree of environmental uncertainty and organizational structure). He discussed: 1) fit as moderation (e.g., effect of the interaction of uncertainty and structure on organizational performance); 2) fit as mediation (e.g., organizational structure as an intervening variable between uncertainty and organizational performance); 3) fit as matching (e.g., fit between uncertainty and structure without regard to effects on performance); 4) fit as gestalts (e.g., Miles and Snow's topology of strategic adaptation); 5) fit as profile deviation (e.g., exploration of the relationship between a firm's deviation from an "ideal" pre-specified profile and that firm's performance); and 6) fit as covariation (e.g., a pattern of decisions "reflecting an internally consistent business strategy" (p. 436)). The significance of Venkatraman's study for this research is that the fit between degree of uncertainty and structure in this study was conceptualized and analyzed as a moderation or interaction effect.

A later section of this chapter (Summary: Support for TCA Transaction Dimensions) examines the various definitions of uncertainty used in empirical TCA research, along with the sometimes contradictory predictions and results for the fit between uncertainty and channel structure.

The final dimension offered by Williamson for categorizing transactions is frequency. The significance of this dimension lies in the fact that specialized structures [internal organization] come at great cost [e.g., capital investment in equipment], and the question is whether the costs can be justified.
This varies with the **benefits** on the one hand and the **degree of utilization** on the other (emphasis added) (Williamson 1985, p. 61).

The benefits mentioned by Williamson are greatest for functions that require specific assets, for the reasons already discussed. The degree of utilization or the volume involved is determined by the frequency dimension. The frequency dimension deals with the scale economy issue, e.g., whether or not the **volume** of products transported is enough to justify the cost of the internal governance (the cost of the firm’s investment in the required assets, e.g., carriers). Or as Williamson put it, "the cost of specialized governance structures will be easier to recover for large transactions of a recurring kind" (1985, p. 60). In explicating the TCA framework, Williamson dealt only with occasional and recurrent transactions because:

> although discrete transactions are intriguing . . . few transactions have this . . . isolated character . . . [and] the difference between one-time and occasional transactions is not apparent (1979, p. 247).

**Summary: Conceptual Research on TCA**

Williamson represented the interactions between the three TCA dimensions (asset specificity, uncertainty, and frequency) and the consequent efficient governance structures by holding one dimension constant and considering variance in the other two dimensions. Table 3 illustrates the efficient governance structure if asset specificity and frequency are varied, while holding uncertainty constant.

If transactions occur either occasionally or recurrently and require nonspecific assets (cells A and C), the most efficient alternative is for the firm to organize the function externally; the nonspecific nature of the assets required indicates that there will be large numbers of sellers willing to perform the function, therefore the firm can contact the seller whose terms and price are most competitive. When the assets required for the performance
of the function become more specific and the transactions are performed occasionally (cell B), even though there are fewer sellers with the specific assets needed, the occasional nature of the transactions makes it difficult for the firm to recover an investment in these assets. In this case, the firm would contract with a seller to perform the function, but would seek to specify the terms of the relationship with a somewhat more elaborate contract than the standardized one used for the nonspecific asset cases described above. Finally, if the function occurs frequently and the assets required are specific (cell D), the volume of transactions and the benefits of internally organizing the function to prevent opportunism by sellers mean that the firm is better off to "make" instead of "buy".

An increase in uncertainty for the conditions in Table 3 would have the following effects. For those transactions/functions requiring nonspecific assets (cells A and C), the most efficient mode of governance or organization remains market ("buy"). Hence, according to the TCA framework, asset specificity must accompany uncertainty for increased transaction costs to occur, a sign that "make" rather than "buy" may be the more efficient structure. The rationale for this effect is that, when nonspecific assets are involved, the large number of sellers that the firm can choose from decreases the requirements for continuity of the relationships between the firm (the buyer) and the sellers. That is, when there are no specialized investments required, the firm has plenty of competing sellers to choose from each time the function must be performed. However, when assets become more specific, there are smaller numbers of sellers possessing the necessary equipment. According to Williamson:

    continuity now matters . . . [and] increasing the degree of uncertainty makes it more imperative to organize transactions within governance structures that have the capacity to "work things out". Failure to support transaction-specific assets with protective governance structures predictably results in costly haggling (1985, p. 79).
<table>
<thead>
<tr>
<th>Frequency</th>
<th>Asset Specificity</th>
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<tr>
<td></td>
<td>Nonspecific</td>
<td>Specific</td>
</tr>
<tr>
<td>Occasional</td>
<td>(A) Buy/Market</td>
<td>(B) Buy/Contract</td>
</tr>
<tr>
<td>Recurrent</td>
<td>(C) Buy/Market</td>
<td>(D) Make/Internal</td>
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</table>
Therefore, increasing uncertainty will mean the more efficient governance or organizational structure for cell B is Make/Internal instead of Buy/Contract (Williamson 1979, 1985).

The TCA framework offers a concise means of achieving an understanding of channel structure and performance. In the words of Frazier, Sawhney, and Shervani (1990):

[TCA] distills a great number of potential constructs into three abstract constructs that appear to have a great importance in explaining levels of... integration (p. 273-274).

**Empirical Research**

Table 4 contains a summary of empirical research on the TCA framework. This section will integrate and summarize the relevant results of the empirical research on TCA.

In reviewing empirical research on TCA, four conclusions emerge.

1) There is disparity in how often, as well as the manner in which TCA dimensions are measured. Most empirical studies measured asset specificity; however, uncertainty has appeared in somewhat fewer studies, and frequency in even fewer still. Not surprisingly, therefore, asset specificity has received a great deal of empirical support, while support for the dimensions of uncertainty and frequency varies from inconsistent to nonexistent. Furthermore, TCA’s predicted interactions between asset specificity, uncertainty, and volume have not been examined, except for a few studies which investigated the interaction of asset specificity and uncertainty.

2) As the Method column of Table 4 demonstrates, descriptive methodology (e.g., surveys, interviews) dominates the extant TCA empirical research.

3) The majority of the research on TCA is not normative, i.e., the research simply assesses whether firms have followed the predictions of TCA in their vertical integration decisions and does not compare the integrated and non-integrated structure to see whether or not these decisions resulted in more efficient performance of the focal function.

4) Existing research on TCA makes no attempt to assess the total of transaction and production costs, a concept that is fundamental to Williamson’s conceptualization.

The discussion of existing empirical research on TCA is organized around these four conclusions.
Support for TCA Transaction Dimensions. The first group of studies discussed in this section are manufacturing studies; the second group are studies of distribution functions.

1. Manufacturing Studies. Klein, Crawford, and Alchian's (1978) in-depth case study of General Motor's vertical merger with Fisher Body investigated only the TCA dimension of asset specificity; the study was strongly supportive of internalization for site-specific manufacturing assets.

Levy's (1981, 1985) results failed to support site asset specificity, but did provide support for physical asset specificity. Physical asset specificity, as signified by the degree of product differentiation and measured by advertising intensity and research/development expenditures, proved to be a significant determinant of vertical integration. Levy also examined uncertainty, but not frequency. Uncertainty was measured by firm and industry level data demonstrating "the degree of unanticipated events," "unanticipated variance in firm sales," and "systematic risk in profits." Results demonstrated a positive relationship between level of uncertainty and the decision to integrate.

Monteverde and Teece (1982) studied the extent to which specific human assets affected the degree of (backward) integration involved in the production of automobile component parts. The degree of asset specificity, measured by ratings of the investment of engineering effort/cost in the development of each component, was positively related to the vertical integration decision. Neither uncertainty nor frequency was investigated in this study.

Masten (1984) measured physical and site asset specificity by scale items in his investigation of the procurement of manufacturing inputs in the aerospace industry. He found strong support for physical asset specificity. Masten also measured complexity (but not uncertainty) by using the firm's ranking of an input's complexity. The ranking was
<table>
<thead>
<tr>
<th>Date</th>
<th>Author(s)</th>
<th>Method</th>
<th>Dataset</th>
<th>Analysis</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978</td>
<td>Klein, Crawford &amp; Alchian</td>
<td>Case Study</td>
<td>GM, Fisher</td>
<td>Qualitative</td>
<td>Supported Specific Assets</td>
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<tr>
<td>1980</td>
<td>Wilson</td>
<td>Interviews Case Study</td>
<td>New England Fish Market</td>
<td>Qualitative</td>
<td>Supported Specific Assets, Uncertainty</td>
</tr>
<tr>
<td>1981</td>
<td>Levy</td>
<td>Compustat data of Mts.</td>
<td>69 Firms in 37 Industries</td>
<td>Least Squares Regression</td>
<td>Supported Uncertainty, Specific Assets</td>
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<td>1982</td>
<td>Monteverde &amp; Teece</td>
<td>Survey</td>
<td>133 Auto Components GM &amp; Ford</td>
<td>Probit</td>
<td>Supported Specific Human Assets</td>
</tr>
<tr>
<td>1982</td>
<td>Anderson</td>
<td>Survey</td>
<td>139 Sales Managers, Electronic Components Industry</td>
<td>Least Squares Regression</td>
<td>Supported Specificity, Specific Human Assets</td>
</tr>
<tr>
<td>1984</td>
<td>Anderson &amp; Schmittekin</td>
<td>Survey</td>
<td>145 Sales Managers, Electronic Components Industry</td>
<td>Logistic Regression</td>
<td>Supported Uncertainty, Specific Human Assets</td>
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<tr>
<td>1984</td>
<td>Masten</td>
<td>Survey</td>
<td>1887 Components, Aerospace Industry</td>
<td>Probit</td>
<td>Supported Complexity, Uncertainty, Specific Assets</td>
</tr>
<tr>
<td>1984</td>
<td>Paley</td>
<td>Interviews Review of Contracts</td>
<td>51 Transactions</td>
<td>Tabulation</td>
<td>Supported Specific Assets</td>
</tr>
<tr>
<td>1984</td>
<td>Walker &amp; Weber</td>
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<td>60 Decisions for Sourcing Auto Components</td>
<td>Unweighted Least Squares of Structural Equations</td>
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<tr>
<td>Date</td>
<td>Author(s)</td>
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<td>Data</td>
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<tr>
<td>1985</td>
<td>Anderson</td>
<td>Survey</td>
<td>159 Sales Districts, Electronic Components Industry</td>
<td>Logistic Regression</td>
<td>Supported Complex'cy/ Uncert'y, Specific Human Assets</td>
</tr>
<tr>
<td>1985</td>
<td>Dwyer &amp; Welsh</td>
<td>Survey</td>
<td>457 Retailers in 10 Industries</td>
<td>LISREL</td>
<td>Supported Complexity/ Uncertainty</td>
</tr>
<tr>
<td>1986</td>
<td>Balakrishnan &amp; Wernerfelt</td>
<td>FTC Line of Business</td>
<td>93 Mfg Industries</td>
<td>Least Squares Regression</td>
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<td>1988</td>
<td>Gatignon &amp; Anderson</td>
<td>Harvard Multinat'l Enterprise Project Database</td>
<td>Entry Modes of 180 US Multinat'l Firms</td>
<td>Multinomial Logit</td>
<td>Supported Specific Assets</td>
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<tr>
<td>1988</td>
<td>John &amp; Weitz</td>
<td>Survey</td>
<td>87 Industrial Firms</td>
<td>Multinomial Logit</td>
<td>Supported TCA Dimensions</td>
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<td>1988</td>
<td>Heide &amp; John</td>
<td>Survey</td>
<td>'199 Mfgs' Agents</td>
<td>Least Squares Regression</td>
<td>Supported Specific Assets</td>
</tr>
<tr>
<td>1989</td>
<td>Klein</td>
<td>Survey</td>
<td>510 Canadian Export Firms</td>
<td>Least Squares Regression</td>
<td>Supported TCA Dimensions</td>
</tr>
<tr>
<td>1990</td>
<td>Klein, Frazier, Roth</td>
<td>Survey</td>
<td>510 Canadian Export Firms</td>
<td>Multinomial Logit</td>
<td>Supported TCA Dimensions</td>
</tr>
<tr>
<td>1990</td>
<td>Heide &amp; John</td>
<td>Survey</td>
<td>175 Mfg Firms</td>
<td>LISREL</td>
<td>Supported TCA Dimensions</td>
</tr>
<tr>
<td>1990</td>
<td>Noordewier, John, Nevin</td>
<td>Survey</td>
<td>140 OEM (Bearings) Purchasers</td>
<td>MANOVA</td>
<td>Supported Uncertainty (Normative Study)</td>
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<td>Date</td>
<td>Author(s)</td>
<td>Method</td>
<td>Data</td>
<td>Analysis</td>
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<tr>
<td>1991</td>
<td>Walker &amp; Poppo</td>
<td>Interviews, Case Studies; Survey</td>
<td>67 Mfg Inputs for Consumer Products</td>
<td>LISREL</td>
<td>Supported Specific Assets (Normative Study)</td>
</tr>
<tr>
<td>1990</td>
<td>Mosakowski</td>
<td>SEC Data</td>
<td>122 Computer Firms</td>
<td>Two-Stage Least Squares Regression</td>
<td>Weak Support for Specific Assets (Normative Study)</td>
</tr>
<tr>
<td>1992</td>
<td>Maltz</td>
<td>Survey</td>
<td>160 Logistics Managers, Four Industries</td>
<td>Logistic Regression</td>
<td>Supported Specific Assets</td>
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</tbody>
</table>
based on the number of details involved in the input's production, "the more details to be accounted for . . . the more dimensions in which something can go wrong" (p. 409) and found support for the importance of complexity in the make or buy decision. According to Masten, "complexity . . . may be used as a proxy for the degree of uncertainty on the production side" (p. 409). However, in the context of Masten's study, complexity appears to be a proxy for physical asset specificity, hence, the support he found for the complexity dimension can more likely be attributed to asset specificity. Frequency was not measured in Masten's study.

Walker & Weber (1984) measured physical asset specificity (measured by the number of suppliers in the market; more suppliers was taken as an indication of less asset specificity) and human asset specificity (measured by scale items assessing amount of production experience). Heide and John (1990) measured both physical and dedicated specific assets by Likert scale items. These two studies had mixed findings regarding asset specificity; Walker and Weber found no effects, while Heide and John (1990) found significant effects for asset specificity. Uncertainty was also investigated and measured similarity in both of these studies as a two dimensional construct: 1) volume uncertainty (fluctuation in volume requirements for manufacturing inputs and uncertain volume requirement estimates for manufacturing components) and 2) technological uncertainty (how often changes in specifications occur and the probability of technological improvements for components). This two dimensional evaluation was an effort to capture the authors' hypothesized mixed effects of uncertainty and refine what the authors felt was Williamson's rather broad explication of the uncertainty construct. Heide and John (1990) contended that, according to Williamson's framework, volume uncertainty should lead to more integration (because internalization facilitates sequential decision making), while Walker and Weber, borrowing from organizational theory (see discussion of the uncertainty construct in
organizational theory under Williamson, hypothesized that technological uncertainty influenced firms toward dis-integration in order to maintain the flexibility needed to facilitate switching suppliers and/or processes in a technologically uncertain environment. These two studies had mixed findings for the uncertainty construct. Walker and Weber found volume uncertainty to be a significantly positive determinant of vertical integration decisions; Heide and John (1990) did not. Technological uncertainty was supported as a deterrent to integration by Heide and John, but not in the Walker and Weber study. Frequency was not investigated in either study.

Balakrishnan and Wernerfelt (1986), also investigated the effect of technological uncertainty on vertical integration. Their model measured technological uncertainty as the mean life of plant and equipment in an industry. Their results indicated that in highly competitive industries characterized by frequent technological change, integration was less desirable. Their study examined neither asset specificity nor frequency.

Noordewier, John, and Nevin (1990) did not examine asset specificity; however they did investigate uncertainty by measuring environmental uncertainty (market turbulence, price/volume uncertainties) using a five item scale. They found that performance under environmentally uncertain conditions was enhanced when, what they termed, relational, rather than market governance structures were employed. The results for frequency, which was examined using a scale item assessing order frequency, were not supportive of the TCA predictions. However, the measurement of frequency in this study does not appear to completely tap Williamson’s (1985) explanation of the concept. Another factor measured by the authors, which they term amount (the total dollar volume of purchases) appears to be a more accurate representation of Williamson’s interpretation of frequency. Results for this variable (amount) were somewhat more supportive of TCA predictions.
Walker and Poppo (1991), who measured physical and human asset specificity with two Likert scale items, found that acquisition of specialized manufacturing inputs (i.e., those which required specialized physical assets for production) tended to be characterized by lower transaction costs when this function was internalized. Neither uncertainty nor frequency were investigated.

2. **Distribution Studies.** Wilson (1980), in a series of unstructured interviews over a period of five years, studied the New England fresh fish market. He found that the market was characterized by a fairly high degree of uncertainty as well as physical and human asset specificity. The uncertainty arose because: 1) market prices for fish tended to be highly variable and 2) the quality of the fish was not able to be determined until after a transaction took place and the fish were off-loaded. The condition of asset specificity arose because the facilities for off-loading fishing boats were few in number and privately owned, which, because of time and distance considerations, effectively prohibited large numbers of buyers and sellers from existing for any given transaction. According to Wilson, since these two dimensions (uncertainty and asset specificity) precluded market exchanges, there arose a rather extensive network of informal contractual arrangements that tended to rely on reciprocity to tie the parties of the exchanges more closely together and lower transaction costs.

Findings on the significance of specific physical and human assets in forward integration (distribution) included one study that, even though it only investigated the TCA dimension of asset specificity, has particular significance in light of the present study’s research question. Palay (1984) examined the governance of relationships between rail freight shippers and carriers. By constructing a series of tables containing tabulated interview data, Palay demonstrated that, as freight required more specialized rail cars, the relationship between the freight shipper and the rail carrier was characterized by increasingly
elaborate, long term contracts, and finally, by vertical integration (i.e., shipper ownership of rail cars).

In perhaps the most extensive investigation of TCA in a distribution context, Anderson (1982) and Anderson & Schmittlein (1984) examined the make or buy decision for the sales function in the electrical components industry, i.e., whether firms used direct sales forces or independent manufacturers’ representatives. Anderson measured human asset specificity (specialized knowledge and working relationships), uncertainty (environmental unpredictability and difficulty of monitoring performance), and frequency (territory density) with a series of scale items. The single best predictor of integration was size of the firm (as measured by number of employees). However, this result seems tautological, since more highly integrated firms would be likely to have a larger number of employees than less integrated firms. Furthermore, a study discussed below (Anderson 1985) found that, when other factors were controlled for, firm size had no effect on integration. The results of Anderson (1982) and Anderson and Schmittlein (1984) supported human asset specificity and internal uncertainty (difficulty of monitoring performance only). External uncertainty (environmental uncertainty) and frequency (territory density) were not significant predictors of level of integration.

Anderson (1985) also investigated sales force integration using a series of scale items similar to Anderson (1982) to measure TCA dimensions. Human asset specificity, internal uncertainty (difficulty of monitoring performance), and the interaction of uncertainty (environmental unpredictability) x asset specificity proved to be strong predictors of integration. Results for the dimension of frequency (sales territory density) were not supportive of TCA predictions. As mentioned above, size of the firm in this study was not significant when all other factors were controlled for.
Dwyer and Welsh (1985) examined only uncertainty, which was measured by using scale items indicating variability of demand. Their results supported a positive relationship between uncertainty (demand variability) and integration.

While not specifically investigating the vertical integration decision, Heide and John (1988) measured human asset specificity using a set of scale items. Their results demonstrated that when there were transaction specific physical or human assets involved, the parties tended to take steps to guard these assets against appropriation. Neither uncertainty nor frequency were examined in this study.

John and Weitz (1988), investigating the degree of channel integration (percentage of products sold directly to end users), measured human asset specificity, uncertainty, and frequency using a series of scale items, some of which were adapted from Anderson (1982). Uncertainty items evaluated both external uncertainty (environmental turbulence/volatility) and internal uncertainty (length of selling cycle, which was assumed to increase the difficulty of assessing performance). The study also measured frequency, both as density of sales territories and product line sales volume. Results supported both asset specificity and internal/external uncertainty. Neither frequency measurement (territory density or sales volume) had an effect on the level of integration.

Anderson and Coughlan (1987), Gatignon and Anderson (1988), Klein (1989), and Klein, Frazier, and Roth (1990) all investigated the nature of distribution channels used for entry into foreign markets. All of the studies, except Gatignon and Anderson, measured physical and human asset specificity using scale items similar to those of Anderson (1985). Gatignon and Anderson used database information to judge asset specificity by assessing the proprietary content and technical sophistication of a product; these factors were measured by advertising intensity and R & D intensity, respectively.
All four of these international studies, except Anderson and Coughlan, investigated uncertainty. Gatignon and Anderson measured uncertainty by rating countries on a "country risk" index, which was based on factors such as governmental stability, restrictions on foreign investment, climate, and cultural dissimilarities. Gatignon and Anderson hypothesized that country risk alone (when assets were nonspecific) would decrease integration. Their definition and evaluation of uncertainty is so broad and contains several factors (e.g., cultural dissimilarities) that do not appear to conform to Williamson's conceptualization of uncertainty that it would be difficult to interpret their results as either supportive or non-supportive of TCA on this dimension. Klein evaluated uncertainty by using Likert scale items measuring two dimensions he designated "uncertainty-complexity" (number of possible sources of uncertainty in the environment) and "uncertainty-dynamism" (rate of change in environment). Klein, Frazier, and Roth measured uncertainty similarly to Walker and Weber (1984) (see discussion above). They hypothesized two dimensions of uncertainty: environmental volatility, or how rapidly the environment changes (expected to encourage integration); and environmental diversity, or how multiple are the sources of uncertainty in the environment. Environmental diversity was expected to discourage integration because integration would make it more difficult to maintain the flexibility needed to facilitate switching suppliers and/or processes. This flexibility was expected to be necessary to prosper in a diverse environment (see discussion above of Walker and Weber's measure of technological uncertainty, as well as discussion of the uncertainty construct in organizational theory research under Williamson). These uncertainty dimensions were measured by scale items developed for the study.

The only one of the four international studies that investigated interaction effects was Gatignon and Anderson, who examined the interaction of R & D/advertising intensity (asset specificity) and country risk (uncertainty).
Neither Anderson and Coughlan or Gatignon and Anderson ostensibly measured frequency. Gatignon and Anderson attempted to account for what they termed "scale effects" by assessing firm size (number of employees), but this measurement appears to have little validity as a measure of potential economies of scale in the context of a distribution channel, and in fact, appears tautological as a predictor of integration (see discussion of Anderson 1982, above).

Klein hypothesized effects for both frequency and volume. The two constructs were measured with scale items: frequency was measured as the number of orders received and the number of shipments; volume was measured as the dollar value of shipments. The measurement of volume appears to tap an important component of Williamson's (1985) conceptualization of the frequency construct, i.e., that of scale economies, or whether the volume of transactions is large enough to support the "specialized structure", i.e., the internal organization of a channel function.

Klein, Frazier, and Roth did not ostensibly measure frequency; in their words, "the frequency variable is not examined because . . . [the interest is only in] recurrent exchange" (p. 198). However, they did measure channel volume (using scale items), a construct which appears to conform to Williamson's (1985) (scale economy) conceptualization of frequency.

All of the international studies found support for the asset specificity dimension as a predictor of level of integration. Klein found support for both of his two dimensional uncertainty factors; uncertainty-complexity increased integration and uncertainty-dynamism decreased integration. Likewise, Klein, Frazier, and Roth demonstrated support for their two dimensional uncertainty factors; environmental volatility led to increased integration, but environmental diversity led to decreased integration. Anderson and Gatignon found support for their hypothesized negative effect of country risk on integration, but found no support for the interaction of R & D/advertising intensity (asset specificity) and country risk.
(uncertainty). Klein’s results supported TCA predictions for both frequency and volume; Klein, Frazier, and Roth found support for channel volume.

Mosakowski (1991) estimated a normative model that demonstrated weak support for an asset specificity x uncertainty interaction. With the assumption that the R & D function was associated with higher levels of specific physical and human assets, as well as uncertainty, she found that the economic performance of firms who contracted for the R & D function was lower than that of firms that performed the R & D function internally. Frequency was not examined in this study.

Maltz (1992) analyzed the make or buy decision for the logistics function of warehousing. All three TCA dimensions were evaluated using scale items. Asset specificity measures included both human and physical asset items; uncertainty items measured environmental uncertainty and unpredictability, as well as difficulty of monitoring performance. The single frequency item measured order frequency.

Results for asset specificity supported the TCA prediction that increasing levels of specific assets was a significant determinant of the decision to use private warehousing. However, the results for the uncertainty and frequency dimensions were either nonsignificant or opposite from TCA predictions. Maltz credits problems with the scales for uncertainty for the lack of significant results on this dimension; the lack of support for the frequency dimension appears to be a function of the fact that, like Klein (1989), Maltz evaluated frequency by measuring number of orders or shipments. This measurement of frequency may or may not be correlated with product (and dollar) volume of orders or shipments. While one might expect order frequency to have an effect on transaction costs, especially in a logistics context, the logic that underlies Williamson’s (1985) explanation of the frequency dimension appears to require that volume transported (for instance) be operationalized to fully tap this dimension.
Summary: Support for TCA Transaction Dimensions. Although empirical support for the TCA dimension of asset specificity appears fairly straightforward and widespread, the other two dimensions (uncertainty and frequency) have not fared nearly as well. Two factors have contributed to this situation: 1) uncertainty and frequency have been examined less frequently than asset specificity and 2) the definition and measurement of the uncertainty and frequency dimensions suffer from a lack of careful attention to Williamson’s original conceptualization of the constructs.

Of the 23 studies examined here, all but three measured asset specificity; 16 examined uncertainty, and only three investigated interactions among the TCA dimensions. Frequency was examined in only 7 studies.

Almost every study that has measured uncertainty has used a different definition, some of which departed considerably from Williamson’s (1975, 1985) definition: uncertainty in the circumstances surrounding the transaction, which makes it difficult or impossible to specify all contingencies for a continuing agreement, as well as making it difficult (and therefore costly) to monitor and enforce the contingencies that are able to be specified. Some researchers have separated the construct into two dimensions, e.g., diversity and volatility; environmental uncertainty and environmental unpredictability; volume uncertainty and technological uncertainty; uncertainty-complexity and uncertainty-dynamism. These two dimensional conceptualizations and measurements clearly have their origins in organizational, strategic management, and/or public policy research and appear to be attempting to deal with the fact that there exist contradictory predictions for desirable governance structures in the presence of uncertainty (see discussion under Williamson). For example, much of the organizational, strategic management, and public policy literature proposes that vertical integration is undesirable when an uncertain environment mandates strategic flexibility. An illustration of this rationale is the necessity to guard against
investments in potentially technically obsolete assets. On the other hand, a discussion by
Balakrishnan and Wernerfelt (1986) maintained that, according to TCA,

the basic argument is that an independent supplier will demand a reasonably
complete long-term contract before committing to investments in an idiosyncratic
asset. As the number of contingencies in the contract goes up, it becomes more
expensive to write, monitor and enforce so that vertical integration becomes more
attractive (p. 348).

In summary, it appears that these multiple operationalizations of uncertainty are
endeavoring to separate uncertainty about events in the environment surrounding the focal
transaction from uncertainty (or volatility) that requires strategic flexibility (e.g.,
technological uncertainty). Careful attention to the original conceptualization and rationale
for the uncertainty construct reveals that there is no logical basis to expect technological
uncertainty, for example, to affect the difficulty of specifying contingencies for a contract
between two parties for the performance of a function, and therefore, no reason to expect
this type of uncertainty to increase transaction costs. An environment characterized by
rapid technological change "does not increase the number of contingencies in a hypothetical
contract . . . it only makes the single contingency [technological obsolescence] more likely"
(Balakrishnan and Wernerfelt 1986, p. 348). Internalizing investments likely to become
technologically obsolete does nothing to decrease the likelihood of that obsolescence.

Other researchers have viewed the construct as being composed of both external
uncertainty (environmental) and internal uncertainty (difficulty of monitoring performance).
There is really no fundamental difference in these dimensions, assuming that both increase
the difficulty of constructing, monitoring, and enforcing agreements between two firms
when a function is externalized and uncertainty exists in the factors surrounding the
transaction. Valid measurement or operationalization of the uncertainty construct requires
that careful attention be directed to the substantive research context. Uncertainty should
be measured or operationalized in such a way that a logical relationship between the
presence of uncertainty and the difficulties of monitoring the agreements with third parties are evident for that context.

In a logistics context, uncertainty and/or complexity of the activities surrounding the function (e.g., pickup/delivery and/or line haul) may make monitoring the terms of the agreement between shipper and carrier (e.g., customer service levels) more difficult (see discussion of Bucklin's *Markets and Services* framework). For example, shipments whose routes traverse an area of the country that experiences adverse weather conditions, or the presence of labor unrest that causes delays in the time required for pickup/delivery or line haul functions may escalate the costs of monitoring and enforcing agreements between shippers and carriers when specialized carrier assets require the continuity of relatively long term agreements. Circumstances that increase negotiating and monitoring of agreements between parties tend to increase transaction costs.

Finally, even though a vital aspect of Williamson's (1971, 1975, 1985) rationale for the TCA framework concerned the interactions among the three TCA dimensions (see discussion under *Summary: Conceptual Research on TCA* and Table 3), very few empirical studies have investigated interaction effects. Only three studies hypothesized and found support for an interaction effect of uncertainty x asset specificity. None of the other interactions posited by Williamson were hypothesized in the existing empirical research on TCA.

Turning to the frequency dimension, the foundation for Williamson's (1985) rationale appears to depend on whether or not enough volume can be generated to recover the firm's cost of investing in internal production or distribution. Therefore, an accurate measurement of frequency in a distribution context requires some measure of the volume flowing through the distribution channel. This volume may or may not be correlated with order or shipment frequency; e.g., many small orders/shipments may or may not generate as much volume as
a few large orders/shipments. Most of the studies that ostensibly measured the frequency construct evaluated this dimension only on the frequency of transactions (order frequency), and not necessarily on volume. This may explain why the results for this dimension are ambiguous.

**Domination of Descriptive Methodology in TCA Empirical Research.** An inspection of Table 4 reveals the following: four of the 23 studies examined here used interviews and/or case studies; one study used both interview/case study and a survey; four studies used secondary data (some of which was obtained from an earlier survey); and 14 used surveys.

According to McGrath and Brinberg (1983), all research methods possess limitations in terms of both internal and external validity. In their words, "all methods are flawed, but different methods are flawed differently" (p. 116). In recommending the use of multiple methods for investigating research questions, McGrath and Brinberg made the point that the use of multiple methods is essential so that "differently flawed methods shore up each others’ vulnerabilities" (p., 116).

While the extant empirical research on the TCA framework, which has employed predominately descriptive methodology, has made valuable contributions, it can be argued that there exists a need for alternative methodologies. According to McGrath (1982), methodological strategies for conducting research fall into four generic classes (I, II, III, and IV, see Figure 1). These classes differ according to which one of three research goals are maximized. The three research goals (A, B, and C, see Figure 1) are delineated by McGrath as:

A) The ability to generalize to the population(s) of interest

B) Precision in control/measurement/manipulation of variables
FIGURE 1  RESEARCH STRATEGIES
Adapted from McGrath (1982, p. 73)
Existential realism, or whether or not the research "[takes] place in settings that are existentially 'real' for the participants [or objects in the system of interest]" (p. 74)

Research goal A) addresses one dimension of external validity; the ability to generalize to a population is contingent on how representative the sample chosen is of the population (Cook and Campbell 1979). Research goal B) addresses "the construct validity of a concept, as reflected in the convergence (and discrimination) of some particular set of operationalizations of it" (emphasis added) (McGrath and Brinberg 1983, p. 115). Research goal C) addresses a second dimension of external validity, i.e., that of realism, or whether or not the context of the research closely "match[es] some real world counterpart" (Lynch 1982, p. 231).

McGrath maintained that a single research study, through the methodological choices that must be made with the purpose of the study in mind, will of necessity, emphasize one research goal, to the detriment of the other two. One of the four generic research classes discussed by McGrath (see Figure 1: I, II, III, IV) included surveys (III, Figure 1), while another of the four classes included computer simulation (IV, Figure 1), and a third included experimental (not computer) simulation (II, Figure 1). Surveys, with their emphasis on representative sampling, seek to maximize population generalizability (research goal A). However, surveys are not able to address realism of context (research goal C), since they rely on participants' furnishing responses "after the fact" in an experiential sense. Computer simulation primarily addresses the realism of context goal (research goal C).

However, when a computer simulation model is used as the basis for experimental analysis, the model is amenable to manipulation which would be impossible, too expensive or impractical to perform on the entity it portrays [e.g., a transportation system]. The operation of model can be studied and, from it, properties concerning the behavior of the actual system . . . can be inferred (Shubik 1980, p. 909).
Since experimental design and concern with construct validity of concepts, i.e., precision in control and manipulation is addressed by research goal B, a computer simulation model used as the basis of an experimental design addresses research goals B (precision in control/measurement/ manipulation of variables) and C (existential realism or realism of context), but not research goal A (ability to generalize to a population of interest).

**Summary: Domination of Descriptive Methodology in TCA Research.** Empirical TCA research has used descriptive methodology, primarily surveys. Survey methodology addresses research goal A, generalizability to the population of interest, but is not able to address research goal B, precision in control and manipulation, or research goal C, realism of context. This study used a computer network simulation model to manipulate variables according to an experimental design. This methodology addressed research goals B, precision in control and manipulation, and C, realism of context, which have not been addressed by the predominant methodology of existing TCA empirical research.

**Evaluation of TCA Normative Performance Implications.** Although a primary component of the TCA framework concerns the normative performance implications of matching governance structure with transaction dimensions, very few studies have investigated this aspect of the framework. Rather, most studies have scrutinized industry or firm practice to see if the TCA prescriptions regarding the match between governance structure and transaction dimensions (see Table 3) exists. Only three of the studies in Table 4 attempted to assess the normative performance implications of TCA.

Noordeemier, John, and Nevin (1990) used three measures of purchasing performance (inventory turnover, product delivery, and product rejections) and found support for the TCA prediction of increasing integration under conditions of uncertainty (measured as market turbulence and price/volume uncertainty). Mosakowski (1990) used total sales and net income (over three years) to measure performance and found some
support for decreased performance when functions characterized by high levels of specific assets and uncertainty (e.g., R & D) were performed external to the firm. However, due to the nature of the data used (SEC data), Mosakowski acknowledged the existence of measurement problems, primarily from lack of detail in the data. Walker and Poppo (1991) demonstrated that transaction costs (which were measured by Likert scales as the difficulty of agreement with suppliers on the allocation of costs for engineering and material changes) for manufacturing inputs requiring specific assets were lower when internal suppliers were used than when external suppliers were used.

Normative research on TCA has important theoretical implications, since from the standpoint of internal validity, exploration of the TCA theoretical framework is deficient without generating hypotheses and attempting to obtain empirical support for the normative performance implications of the framework.

Normative research also has significant managerial ramifications for "make versus buy" decisions, since "managerial decision rules based on TCA are meaningful only if they can be demonstrated to enhance performance" (Noordewier, John, and Nevin 1990, p. 90). In the context of the present study, i.e., the issue of transportation by private fleet versus transportation outsourcing, discovering what factors impact the decision necessitates consideration of the normative performance implications of the interaction of those factors.

**Summary: Evaluation of TCA Normative Performance Implications.** Research on the normative performance implications of the TCA framework has important theoretical and managerial implications and is clearly in need of exploration. The results of this study make a contribution to this exploration, since the dependent variable in the research design was performance (i.e., efficiency), and not simply the match of structure (make or buy) with transaction dimensions.
Assessment of the Sum of Transaction and Production Costs. Another important component of the TCA framework is the proposition that the basis for the make or buy decision is not simply the level of transaction costs, but instead, the total of transaction and production costs.

Williamson (1985) contended that if, for example, the result of internalizing a function was a decrease in transaction costs, and a concomitant increase in production costs (e.g., due to dis-economies of scale or scope) which caused a net increase in the total of transaction and production costs, then internalizing the function was not appropriate. Conversely, if a firm could realize decreased production costs by contracting with an outside supplier (who, by combining the volume from several firms, is able to realize scale economies), only to experience an increase in transaction costs (e.g., costs incurred in negotiation and re-negotiation of the terms of the agreement, monitoring and enforcement of supplier performance) that results in a net increase in the total of transaction and production costs, then externalizing the function was an unsatisfactory option.

Transaction costs may be difficult to measure; these are primarily indirect costs. Production cost data may be proprietary, and, therefore, unavailable. Possibly because direct measurement of these costs is problematic, none of the empirical research on TCA has attempted to directly assess the total of transaction and production costs. Furthermore, since it is impossible to manipulate variables (e.g., levels of specific assets, uncertainty, frequency) and measure the resulting levels of transaction and production costs when using descriptive methodology, no research has compared the total of transaction and production costs for various levels of asset specificity, uncertainty, and frequency. Manipulating the transaction dimensions of TCA in a controlled environment would provide the opportunity for assessing the variation in the total of transaction and production costs.
Summary: Assessment of the Sum of Transaction and Production Costs. None of the existing empirical TCA research explicitly examines the total of transaction plus production costs or the total of these two costs under various transaction conditions. The modelling and computer simulation of a transportation network combined with an experimental design in this research provided a realistic, yet controlled environment in which to address this issue.

Summary: Empirical Research on TCA

Existing empirical TCA research:

1) Lacks either uniform results or any results on the three TCA transaction dimensions and their interactions

2) Has been conducted using primarily survey methodology

3) Requires exploration of the normative performance implications of the theoretical framework

4) Has not adequately addressed the total of transaction plus production costs that is suggested by Williamson’s conceptualization of the TCA framework

The next section discusses and consolidates the five frameworks discussed in the previous four sections to form the conceptual foundation for the present study.

CONSOLIDATION OF FRAMEWORKS - CONCEPTUAL FOUNDATION FOR PRESENT STUDY

A comparison of the issues discussed in the summaries of each of the first four conceptual frameworks (characteristics of goods, scale economies, functional spin-off, and markets and services) used in marketing to investigate the subject of channel structure reveals that most of the constructs contained in these frameworks can be viewed simply as operationalizations of TCA dimensions.
Bucklin's markets and services factors (number, size, geographical dispersion of customers; customer service requirements, e.g., delivery time, order size, and availability of products) can be viewed as manifestations of uncertainty/complexity and/or frequency/volume characteristics surrounding distribution transactions, particularly in a logistics context.

The fourth characteristic of goods (adjustment or service required to meet customer needs) carries with it the implication that specific manufacturing and/or distribution assets may be required (due to product complexity); alternatively, this characteristic may be an indication of transaction volume or complexity (e.g., requirements for frequent shipments).

The first three characteristics of goods (amount of search prior to purchase, purchase frequency, time required to consume), as mentioned previously, are closely associated with each other, and could be seen as evidence of complexity, particularly in a logistics context (e.g., nature of deliveries to retailers; intensive versus exclusive distribution).

The scale economies/functional spin-off framework, which emphasizes production costs, clearly has a place within the TCA framework, since TCA advocates economizing on the total of production and transaction costs. In addition, the fifth characteristic of goods, gross margin (difference between selling price and cost of goods sold) is related to scale economies because economies of scale (either in production or distribution), will lower the cost of goods sold, thereby increasing the gross margin.

This section has demonstrated that the constructs present in the other four frameworks used in marketing to explain channel structure configurations can be viewed primarily as lower order constructs which are subsumed under the higher order TCA constructs of asset specificity, uncertainty, and frequency. For this reason, the TCA constructs and the relationships among them formed the conceptual basis for this study.
LOGISTICS RESEARCH

CHAPTER I considered why logistics, particularly transportation efficiency, has substantial economic implications for the US, and pointed out a number of changes that have occurred in the transportation industry since deregulation. This section of CHAPTER II reviews logistics research which has considered the make or buy decision.

This review is structured according to the categories contained within Mentzer and Kahn’s (1993) framework for logistics research. The framework suggests four categories of research: normative literature/literature reviews, exploratory studies, methodology reviews, and hypothesis testing. According to Mentzer and Kahn, normative literature/literature reviews and exploratory studies serve the function of providing substantive justification for research in logistics by describing empirical regularities. However, Mentzer and Kahn maintained that only rarely does logistics research employ an approach which utilizes hypothesis testing, reliability and validity appraisals, and rigorous analytical techniques. They contended that this approach is required for the development and maturation of logistics research.

Research reviewed in this section will fall into three of the four categories enumerated above: hypothesis testing studies, normative literature/literature reviews, and exploratory studies. The review will be divided into three segments.

The first segment will review studies that either generate or generate and test hypotheses. These studies are relevant to the present research question because of their explicit or implicit use of a conceptual framework similar to that of the present study. The second segment will summarize ten studies that are either normative studies, literature reviews, or exploratory studies (e.g., surveys or case studies of managerial practice). Three of the studies discuss outsourcing issues for logistics functions in general; the other seven studies examine outsourcing issues for the transportation function in
particular. In addition, the second segment will examine three case studies which detail the actual implementation of logistics or transportation make or buy decision outcomes.

The reviews and exploratory studies discussed do not represent an exhaustive compilation of the available literature on outsourcing of logistics functions. Such a compilation would be prohibitively lengthy, given the academic and managerial interest in this substantive area. However, the studies chosen effectively illustrate the relevant issues.

The final segment summarizes the logistics research reviewed in the first two segments and indicate its relevance to the present research.

**HYPOTHESIS TESTING/GENERATING RESEARCH**

This segment discusses three studies that, either explicitly or implicitly, made use of a conceptual framework similar to the one used in the present study and utilize a hypothesis testing (or hypothesis generation) approach.

In an exploratory study that surveyed the use of "facilitating agencies" used in export channels, Reid (1982) measured asset specificity and frequency (using scale items) and found that higher levels of specific human assets and frequency made firms more likely to internalize export channel activity. Frequency was measured in this study by volume of exports, as well as transaction frequency (e.g., number of orders, number of shipments). This measurement of frequency (both volume and number of orders) captures the scale economies/production cost aspect of Williamson's (1985) frequency rationale, as well as the customer service considerations (e.g., order cycle time, frequency of shipments) that are important in a logistics context.

Although not an empirical article, Beier (1989) made explicit use of the TCA framework to generate hypotheses delineating the effects of specific human assets (i.e.,
learning by doing in the context of shipper-carrier relationships) and frequency on the nature of contracts between shippers and motor carriers. Beier maintained that:

Williamson's logic can easily be applied to the logistics transaction. To use his terms, the relationship between shipper and carrier can be characterized by recurring and frequent transactions in the form of regular shipments. Specialized assets may also be present in the form of unique rolling stock. . . . Where there are no (specialized) investments on the part of either party, nor a need for frequent interaction, then transportation services are likely to be traded on an open or spot market (p. 76).

Because of his explicit use of the TCA framework, Maltz (1992) has already been reviewed in the section of this chapter which discussed empirical research on TCA. Maltz dealt with the logistics function of warehousing, using regression to model the transaction dimensions that predicted firms' propensity to use private versus public warehousing. Although he measured all three TCA dimensions, as well as the interaction of asset specificity and uncertainty, Maltz only found support for the asset specificity dimension.

**Summary: Hypothesis Testing/Generating Research**

These three logistics studies exhibited several of the deficiencies noted in the previous section on empirical TCA research, i.e., use of descriptive methodology and failure to measure all TCA dimensions and interactions. However, these studies did provide support for the TCA dimensions of asset specificity and frequency in a logistics make or buy context.

**Normative Studies/Literature Reviews; Exploratory Studies**

The three studies reviewed in the first part of this segment discuss the make or buy decision for logistics functions in general. The seven studies in the second part of the segment discuss the make or buy decision for transportation. The final part of this segment
contains three case studies, which detail the implementation of a make versus buy decision outcome for logistics/transportation in three firms.

**Logistics Outsourcing Studies**

Ferni (1989) surveyed the extent of outsourcing of retail distribution services in the British retail industry. The main reason for contracting for distribution services proved to be a desire for cost reduction. External distribution specialists were often able to perform the distribution functions at a lower cost due to economies of scale. These specialists, by consolidating the volumes from several firms, were able to negotiate discounts on fuel, vehicles, and ancillary equipment. On the other hand, firms in the survey that internalized distribution services felt that they were better able to monitor costs and customer service performance, as well as to realize economies of scale, by internalizing the functions.

Cavinato (1989) conducted interviews with 137 manufacturers to explore the reasons for outsourcing production or distribution functions (e.g., production of manufacturing inputs, distribution of finished or semi-finished products). In a finding similar to Ferni’s retail distribution outsourcing study above, Cavinato’s results indicated that cost considerations were the primary reason the manufacturing firms outsourced. Capacity constraints and the desire to avoid performance of technically difficult procedures were additional reasons given for outsourcing. If one makes the assumption that technically difficult procedures require specific assets, outsourcing of these procedures appears to contradict the asset specificity proposition of TCA. This contradiction illustrates the necessity for developing and building a theoretical foundation from which to view logistics make versus buy issues.

Some of the disadvantages and risks associated with outsourcing that were mentioned by Cavinato’s survey respondents include potential competition from a vendor
that "learns by doing" (i.e., acquires specific human assets) as well as a loss of research and development strength.

New technologies . . . as well as development of cost reduction advantages often occur because the research, development and engineering are in close proximity to the actual production [i.e., site specific assets]. . . . [M]any [firms] . . . indicated that these advantages were diminished when their firms outsourced (p. 20).

Note the similarity of these results regarding the organization of the R & D function to those of Mosakowski (see Evaluation of TCA Normative Performance Implications), who found that outsourcing of the R & D function decreased firm performance.

Sheffi (1990), in an article which illustrated prevailing trends in third party logistics, characterized the corporate decision to outsource logistics functions as "a variation of the classical make/buy; companies can either invest . . . or contract this function out" (p. 35). Sheffi went on to state that the general trend in outsourcing was for both very small and very large firms to internalize logistics functions, with firms in between these two extremes being the primary candidates for outsourcing.

Echoing the production cost considerations of TCA (and the scale economies/functional spin-off framework), Sheffi recommended that firms look at their logistics departments and decide whether to build or "rent" modern logistics capabilities. Avoiding this decision means, in many cases, leaving significant monies on the table and, more importantly, falling behind on customer service and production costs (p. 36).

Summary: Logistics Outsourcing Studies

The issue contained in the three studies just discussed which is relevant to the present research, is the fact that a majority of the respondents in these studies cited cost reduction as the principal reason for outsourcing, an empirical finding which provides corroboration for the economizing emphasis of the TCA framework. An additional issue
mentioned is the emphasis on customer service considerations (e.g., order cycle time) in logistics outsourcing decisions (Fernie 1989; Sheffi 1990).

Transportation Outsourcing Studies

The seven studies discussed here consider some issues that are relevant to the specific context of the make or buy decision for transportation.

McGinnis (1978) used cluster analysis to investigate whether freight markets (i.e., shipper transportation requirements) could be segmented. This study is relevant to the present research because several of the factors examined by McGinnis as segmenting variables include items which are included in the present study's conceptual framework. McGinnis found that the main source of competition for common motor carriers (i.e., for hire carriers) were private fleets operated by shippers who marketed high value products to customers who demanded a high level of customer service. High value products were discussed under the characteristics of goods framework (assuming that high value products implies products with high gross margins), and customer service levels were discussed under the markets and services framework.

Cavinato (1984) conducted an analysis of transportation contracts, as well as a series of interviews, to examine the benefits and drawbacks of agreements between shippers and carriers. One of the drawbacks mentioned specifically by Cavinato was the transaction cost of contracting activities.

The development of contract carriage arrangements requires an...investment of time and effort...[for example] carefully developed proposals, evaluations, and negotiation. Thus, the act of contracting can be costly (p. 11).

Cavinato goes on to discuss some factors which might affect the contracting process, i.e., be responsible for increasing the cost of contracting.
Differences in commodity characteristics... [for example] food items (perishable...), hazardous materials... liquid bulk materials (needing special equipment),... all require specific contract features. Similarly, the number of origin points, routes, and delivery points may influence the need to specifically identify and account for the differences between contracts (p. 11).

Cavinato's study also contains a list of what he terms "key transportation service contract components" (p. 12). One of these key contract components discussed the necessity for force majeure clauses, which specify contract terms in the face of catastrophic events of nature.

Cavinato's discussion of contracting costs, and his identification of commodity characteristics and key contract components, which are clearly manifestations of asset specificity and uncertainty, make this study relevant to the present research.

La Londe, Cooper, and Noordewier (1988) and La Londe and Cooper (1989) surveyed logistics management practices and attitudes pertaining to customer service issues. Although both of these studies encompassed all logistics functions, only the findings concerning transportation activities will be discussed here.

An indication that third party logistics relationships are an important aspect of the customer service issue was the finding that the shippers surveyed rated pricing structure (e.g., rates and discounts) and consistency of service (e.g., pickup, delivery, and total transit time) as the most important factors in their selection of a third party transportation carrier.

When asked for their projections about the changes in the proportion of shipments which move on private versus common/contract motor carrier, shippers indicated that, by 1995, they expected there to be a decrease in the proportion of shipments moving on private carriers and a concomitant increase in shipments on common and contract carriers. Overall, these results indicate a relative change in logistics channel structure from more to
less integrated. However, additional structural implications discussed by the authors also included the fact that

there will be a shift from a purely transactional relationship between buyer, seller . . . , more of, a contractual relationship . . . [as well as] renewed pressures for shipments direct from plant to customer (La Londe, Cooper, and Noordewier 1988, p. 153).

The implications from these studies are: 1) logistics channel structure is undergoing a shift, not only away from integration, but also toward more long term agreements (i.e., contracts) between shippers and third party logistics providers, and 2) logistics channels are experiencing increased service demands. An examination of the tradeoff of transaction and production costs from the perspective of TCA could facilitate a greater understanding of this projected structural change.

Stock (1988) discussed the issue of outsourcing the transportation function in the post-deregulation transportation industry. His examination of benefits to shippers outsourcing transportation functions is relevant to the present study because of its accentuation on scale economies. The benefits identified by Stock included higher productivity, increased marketing and operational flexibility, and increased profitability. According to Stock, outsourcing enables shippers to redeploy funds from investment in transportation equipment to manufacturing or product development investments, and if the third party provider of transportation enjoys economies of scale, outsourcing may allow shipper firms to reduce costs, even while improving customer service levels.

McGinnis (1990) compared empirical findings on factors affecting the transportation choice decision for pre-deregulation and post-deregulation environments. Pre-deregulation studies indicated that service factors far outweighed cost factors in their influence on transportation choice (i.e., private versus for hire carrier selection). Post-deregulation results exhibited a somewhat, but not radically, different picture; although service
considerations are still emphasized somewhat more than cost considerations, cost considerations have assumed a greater importance in the transportation choice decision since deregulation. According to McGinnis, one reason for this increased importance for cost considerations in the post-deregulation environment is that "tariffs and rules have been replaced by the negotiation of price/service packages (p. 18)." In other words, before deregulation, price (and to some extent service) was fixed as a result of government regulation of the motor carrier industry. This study's finding of a shift in post-deregulation decision processes has relevance to the present study, since this change in the nature of the decision process could have transaction cost implications.

Bardi and Tracey (1991) surveyed a sample of firms in the US to determine: 1) how prevalent outsourcing of transportation functions was, and 2) the reasons firms outsourced these functions. Transportation functions examined by this study included: international shipping, freight tracking/auditing and carrier selection/contracting/negotiating. Bardi and Tracey found that more than 75% of the firms they surveyed outsourced some transportation functions. Although the size of firm was not correlated with outsourcing practice, the results did indicate that annual transportation expenses were related to outsourcing; the higher the annual transportation expenses, the less likely a firm was to outsource transportation functions. The most frequently cited reason for outsourcing was anticipation of cost savings, and more than one-half of the firms that outsourced functions did experience transportation costs savings. The most frequently cited problem with outsourcing was service consistency.

This study underscores the managerial importance of the issue of outsourcing, as well as providing evidence of the recurring emphasis on cost or efficiency considerations in firms' decisions concerning make or buy decisions.
Summary: Transportation Outsourcing Studies

In summary, the seven studies discussed in this section have:

1) Provided substantive evidence that the conceptual framework used in this study (TCA) is a useful perspective from which to explore the transportation make or buy decision (e.g., Cavinato 1984, 1989; McGinnis 1978)

2) Presented empirical evidence of structural changes that have occurred and continue to occur in the transportation industry following deregulation, changes which could have potential implications for transportation make or buy decisions (e.g., La Londe, Cooper, and Noordewier 1988, La Londe and Cooper 1989, and McGinnis 1990)

3) Underlined the managerial interest in and importance of the transportation make or buy decision (e.g., Stock 1988; Bardi and Tracey 1991)

Case Studies

The first case study discussed concerns a firm that moved from internally organized logistics functions to outsourcing the functions; the second case study considers the make or buy decision for a small start-up firm requiring logistics services; and the third case study involves a firm’s decision to discontinue its operation of a private motor carrier fleet and outsource the transportation function.

Bishop and Wunning (1988) detailed the reasons and results of Fisher Controls’ move from internal to external distribution of their products (replacement industrial valve parts). Among the reasons cited for the change in distribution structure was Fisher’s lack of efficiency and consistency in providing optimal customer service performance in distribution operations. Fisher Controls entered into an agreement with Caterpillar Logistics Services, Inc. (CLS), a third party logistics service provider, to provide distribution services for all of Fisher’s products. Fisher realized substantial cost savings in their distribution operations because
Fisher pays only for the services they utilize. By combining the volumes of a number of clients, [CLS's] cost per unit of throughput is much lower. Fisher realized immediately the economies of scale that CLS enjoys (p. 9).

Buckner, Sigworth, and Leith (1989) discussed the events that led to Tektronix Logistics Services providing world-wide distribution services to E-Machines, a small manufacturer of large screen displays for Macintosh computers. When E-Machines, a small start-up company, experienced an unexpected surge of orders for their product following a product demonstration at a computer trade show in 1986, they had no investments or experience in distribution operations. E-Machines required an immediate world-wide distribution arrangement to meet its commitments.

[Tektronics Logistics Services] provided an economical solution. . . . The partnership with a multinational company [Tektronics Logistics Services] has provided allowed us to control costs by sharing international containers (and) consolidating local freight (p. 352).

Lanigan and Murray (1993) presented the successful substitution of B.F. Goodrich's private motor carrier fleet with a third party transportation provider, Schneider National Carriers, Inc. Within the organization, the B.F. Goodrich fleet operated as a profit center, so that cost considerations were the primary drivers in the decision of whether to maintain the private fleet or outsource the transportation function.

A comparison of cost per mile for the private fleet and third party alternatives was done in 1984, 1987, and 1990. The cost advantage clearly went to the private fleet in 1984. In 1987, there was still a $0.12 per mile advantage for the private fleet. However, in 1990, the comparison revealed a advantage of $1.06 per mile for the third party alternative, and the decision was made to cease maintenance of the private fleet and enter into a third party relationship with Schneider National Carriers, Inc.

Although the agreement with Schneider National Carriers, Inc. consisted of extensive negotiations and continues to include thorough performance monitoring by B. F.
Goodrich, the company reported a cost savings over the three years since implementation of greater than $1 million.

Summary: Case Studies

The three case studies reviewed in this section illustrated the relevance of the make or buy decision in a logistics/transportation context by demonstrating three implementations of outsourcing that were viewed as successful by the firms involved. In addition, the case studies provided additional support for the importance that cost reduction, i.e., efficiency considerations, plays in these decisions.

SUMMARY: LOGISTICS RESEARCH

Although there were relatively few studies in logistics that employed a hypothesis testing approach to examine the make or buy decision, the hypothesis testing studies reviewed here provide some support for TCA constructs in the context of the logistics make or buy issue.

Respondents in a number of the normative or exploratory studies reviewed emphasized cost reduction as a critical factor in the make or buy decision, a finding which provides corroboration for the economizing emphasis of the TCA make versus buy framework. Furthermore, various normative studies or literature reviews provided empirical evidence of variables which ostensibly represent constructs from the conceptual framework of this study. Examples of this are McGinnis' (1978) customer service requirements (uncertainty) and Cavinato's (1984) contracting costs (transaction costs) and commodity characteristics (characteristics of goods requiring specific assets). Finally, the exploratory case studies characterized the managerial relevance of the logistics make or buy issue and the importance of the customer service considerations (e.g., order cycle time) to this

In summary, the findings of the hypothesis testing research, as well as the normative studies, literature reviews, and exploratory studies discussed in this review indicate that the conceptual framework selected for this study is a useful perspective from which to examine the transportation outsourcing decision. Finally, the exploratory case studies discussed are illustrative of the managerial relevance of research examining this issue.

**SIGNIFICANCE OF THE PRESENT STUDY**

This final section summarizes the existing conceptual and empirical research on the issue of make or buy that has been discussed in this chapter and discusses how the present study contributed to existing knowledge.

Five frameworks have been used in marketing and logistics literature to address the issue of channel structure, specifically the make or buy decision. A previous section of this chapter discussed the five frameworks and indicated that four of these can be subsumed under TCA.

The empirical research on transaction cost analysis exhibits a lack of uniform results (or no results) on TCA transaction dimensions and the interactions among the dimensions; has been conducted using primarily survey methodology; requires exploration of the normative performance implications of the TCA framework; and has not adequately addressed the issue of the total of transaction and production costs.

The majority of logistics research has failed to utilize hypothesis testing, neglected reliability and validity appraisals, and used analytical techniques, such as descriptive
statistics, that lack rigor. The research design and data analysis in this study addressed this deficiency.

Logistics, particularly transportation efficiency, has substantial economic implications for the US. The level of interest in the managerial issue of outsourcing business functions in general, and logistics functions in particular, suggests that the performance implications of the transportation outsourcing decision have significant managerial relevance.

In summary, the contributions of this study fall into three categories: conceptual, methodological, and managerial. Conceptual contributions included exploration of the five frameworks that have been applied to the make or buy issue in marketing and logistics, along with the conclusion that four of these frameworks can be subsumed under TCA; operationalization of all relevant constructs in the TCA framework and an examination of the appropriate interaction effects; investigation of the normative implications of TCA; and utilization of TCA and a hypothesis testing approach to examine a logistics research problem. Methodological contributions included the use of an alternative methodology (computer simulation and experimental design) to address some of the vulnerabilities of the survey methodology employed in the existing research, and examination, through the use of the realistic but controlled environment of the simulation model, of the effects of TCA constructs on the total of transaction and production costs. Managerial contributions included an investigation of what factors influence the operational issue of whether a firm should utilize private motor carriers or outsource transportation service requirements.

The next chapter discusses previous applications of computer simulation methodology in logistics research, defines the variables and demonstrates how each variable was operationalized, describes the simulation model used for this research and explains how
the model was verified and validated, develops the research hypotheses, and specifies the research design and method of analysis.
CHAPTER III

RESEARCH METHODOLOGY

This chapter describes the methodology of this research study. The first section discusses the procedure for simulating a system, relating each stage of this procedure to the present research study. The second section discusses previous applications of computer simulation in logistics research. The third section defines the variables used in this study and discusses how each was operationalized. The fourth section presents the research hypotheses and specifies the research design and analyses that were used to test the hypotheses. The fifth section describes the network simulation model that was used to test the research hypotheses and discusses parameterization, verification, validation of the model, as well as some issues that involve the accuracy and reliability of the data produced by the simulation model.

THE SIMULATION PROCESS

Lee, Moore, and Taylor (1990) recommended that the following steps be followed when simulating a system (see Figure 2): formulate the problem; specify the performance of the system (decision rules and system parameters); develop a computer model of the system; validate the model; design experiments to investigate the system; perform simulations; assemble simulation output; and analyze simulation output.

Step one in the above procedure, problem formulation, was accomplished in CHAPTER I, with the present research problem being stated: how is the cost of motor carrier transportation for a product’s distribution from manufacturer to customer affected by the organizational structure (private fleet versus outsourced transportation) and the characteristics of the activities related to transporting that product.
Formulate Problem

Specify Performance Criteria, Decision Rules, and System Parameters

Develop Model

Validate Model

Design Experiments

Perform Simulations

Assemble Output Results (Model Operating Statistics)

Analyze Results

FIGURE 2
STEPS IN THE SIMULATION PROCESS
Adapted from Lee, Moore, and Taylor (1990, p. 535)
Steps two and three in the simulation procedure involve specifying the performance of the system of interest and developing a computer model of that system. The specifications for the simulation model that was used in this study and the model development process are discussed under MODEL CONSTRUCTION AND MODEL PARAMETERS and Activity Based Costs for the Transportation Network Model in the section, NETWORK SIMULATION MODEL.

Step four, model validation, is discussed under MODEL VALIDATION in the section, NETWORK SIMULATION MODEL. The steps outlined for verification and validation of the model in this study are adapted from Van Horn (1969), Naylor and Finger (1967), and Law and Kelton (1982).

Steps five, seven, and eight (design experiments to investigate the system; assemble simulation output; and analyze results) are discussed in the RESEARCH HYPOTHESES - RESEARCH DESIGN section and the analysis of the simulation output (step eight) is presented in CHAPTER IV. The relevant aspects of the step six (perform simulations) are discussed under SIMULATION in the NETWORK SIMULATION MODEL section.

COMPUTER SIMULATION APPLICATIONS

There are numerous applications of computer simulation modelling of components of logistics/distribution systems, as well as complete systems. Two characteristics of the activities involved in these systems make them particularly suitable for modelling: 1) these activities generate data that are relatively quantifiable, and 2) they involve networks of "fixed facilities and connecting linkages" (Mentzer and Cosmas 1979, p. 37). The size and complexity of these systems, their stochastic nature, the level of detail necessary for investigation, and the inter-relationships among the system components make simulation
modelling a particularly appropriate modelling approach. Finally, the fact that "real life" controlled experimentation of logistics/distribution systems is not possible makes experimental designs using computer simulation models an attractive alternative for understanding system behavior (Geoffrion 1975, 1976; House and Karrenbauer 1978; Mentzer and Cosmas 1979). According to Shycon and Maffei (1960),

simulation provides the ability to operate some particular phase of a business on paper - or on a computer - for a period of time, and by this means to test various alternative strategies and systems. . . . [D]istribution . . . problems . . . have been solved in a remarkably accurate fashion by simulation (p. 244).

This section discusses eight simulation models that have been used to investigate logistics/distribution systems.

**SHYCON AND MAFFEI MODEL**

Shycon and Maffei (1960) developed a simulation model to solve distribution problems at H. J. Heinz Company. The system consisted of warehouses, inventory policies, and transportation modes. Although there was no explicit consideration of experimental design, the model simulated a year of system operation for a number of different warehouse configurations and compared the distribution costs for each configuration.

**FORRESTER MODEL**

Forrester (1961) developed a model that simulated a firm's production/distribution system. The principal contribution of the model was its demonstration of the effect of variations in customer demand on inventory levels throughout the system. Forrester performed no statistical analyses of the system's response, using primarily graphical analyses, and did not utilize an experimental design. Concerning model validation, Forrester felt the primary purpose of the model was to facilitate the design of better management
systems. According to this criterion, the validity of the model was able to be determined only after it had been used for system design.

**LREPS Model**

LREPS (Long Range Environmental Planning Simulator) was a dynamic simulation model developed by Bowersox et al. (1972) at Michigan State University to evaluate system cost and service response to different distribution system designs. The model incorporated the logistics elements of transportation, warehousing, inventory, and communication for three echelons of a distribution system (manufacturer, wholesaler, and retailer), and measured system responses of total cost and customer service (delivery performance). Variations in demand and lead time formed the independent variables used for the full factorial design. Analytical techniques included: ANOVA, Chi-Square tests, Theil’s Inequality Coefficient, spectral analyses, graphical analyses, and factor analyses. Experimental results of a series of simulation experiments indicated that lead time uncertainty increased system cost and decreased delivery performance.

Bowersox et al. performed an array of analyses to examine the model’s validity, which they maintained was indicated by: 1) the model’s long-term stability, 2) sensitivity of model response to model assumptions, and 3) comparison of model output with historical output. LREPS appeared to possess long-term stability and the model’s response variables (total cost and delivery performance) proved to be relatively insensitive to the methods used for generating demand and the selection of product categories used in the analyses. However, the results for the comparison of model output with historical output were less conclusive, leading the authors to state that “the validity of the model’s predictive ability has not been established” (p. 184).
WRIGHT MODEL

Wright (1971) simulated the operation of a motor carrier firm to investigate customer service policies and the effects of resource investment policies on growth and fluctuation in sales levels. Although an explicit experimental design was not used, there was a systematic effort to test alternative operating policies. Model validation was accomplished by using data from company records, along with an estimate of the service-sales growth relationship. Although point estimates for the company’s actual results were poor, the trends of simulated sales growth and actual sales growth were consistent. The most significant result of the study was the observed reduction in profits caused by fluctuation in order rates at either of the firm’s two terminal locations.

BALLOU MODEL

Ballou (1976) investigated a simulation of a chemical company’s inventory control system in order to examine the sensitivity of the company’s physical distribution system to temporal delays in order transmission, order preparation, and delivery to warehouse and customer. There was no attempt to statistically validate the model, and the investigation was not conducted according to a formal experimental design. One computer run was generated for each time lag change investigated. A consequence of this sample size ($n = 1$) was that the reliability of system response could not be computed.

Measurement of system response included total cost, stockout rate, stock record accuracy, and forecast accuracy. A potential validity problem with this model is that the simulation did not model two significant elements of the system: system controls on minimum and maximum inventory levels that prevented stockouts and small orders, respectively. Since the model was concerned with system performance, failure to represent
these elements seems to represent somewhat of a compromise with respect to the model's validity.

MENTZER AND COSMAS MODEL

Mentzer and Cosmas (1979) used GERT (Graphical Evaluation and Review Technique) to model a motor carrier transportation network for the purpose of discovering the most profitable route to select from four possible routes, each with varying probabilities of empty, less than truckload (LTL), or full truckload (TL) backhauls. Time delays due to bad weather and labor unrest complicated the route decision. Each route was simulated 1000 times to discover which would result in the highest expected profit.

Two factors make Mentzer and Cosmas's simulation model particularly relevant to the present research: 1) Mentzer and Cosmas simulated a motor carrier transportation network, and 2) they used GERT, a precursor of SLAMII, the simulation software which was used in the present research.

KARRENBAUER MODEL

Karrenbauer (1980) simulated a corporate logistics system and conducted experiments of alternative communication technologies and alternative replenishment shipment policies. Response variables included: net revenue, cost per unit sold, average inventory, order cycle time, and transportation cost per unit.

The experiments utilized a two factor design; each factor had three levels, resulting in a total of 3² or nine cells. Five runs (replications of one year's duration) of the model were completed for each cell; both main effects and interactions were investigated. The replications allowed the computation of the reliability of the simulation responses. ANOVA and Duncan's multiple range test were used to analyze simulation output.
Karrenbauer's research consisted of several elements that represented notable progress with regard to computer simulation experiments. His validation procedures were an improvement over earlier model validation efforts (especially those that attempted no validation). The use of a formal experimental design, the analysis of model output to investigate both main effects and interactions, the use of multiple comparison procedures, and the computation of the reliability of the simulation response indicated that Karrenbauer's research was methodologically more sophisticated than previous simulation research on logistics systems.

GOMES - GPM

Gomes (1988) used the Global Planning Model (GPM) to investigate the performance effects of demand and/or materials management and demand uncertainty and JIT systems for physical distribution and/or materials management. GPM was a dynamic simulation decision support system, developed by a group of Virginia Tech students directed by Dr. John T. Mentzer (Mentzer and Gomes 1991). The model contained a collection of subsystems that could be configured to represent a number of logistics system designs. Gomes noted that since the external validity of the GPM had been previously examined, validation procedures for his study were limited to verification of the uniformity and independence of the model's random number generators.

Gomes used a $2^4$ factorial design and ANOVA and ANACOVA to investigate main effects and interactions; Scheffe's method was used for multiple comparisons of cell means, and Fisher's Least Significant Difference method was used for pair-wise comparisons. A sample size of ten replications per cell permitted calculations of reliability for simulation responses. It was demonstrated that this sample size produced a confidence level of 95% or greater in the estimates of system response.
This research demonstrated a relatively high level of methodological sophistication, and the empirical results obtained were significant in that they were not generally supportive of traditional knowledge concerning the effects of JIT on logistics systems.

**SUMMARY OF LOGISTICS SIMULATION MODELLING**

This discussion of the modelling efforts of a number of researchers demonstrated that logistics/distribution systems lend themselves to investigation through simulation modelling. The characteristics of logistics/distribution systems described at the beginning of this section, along with the descriptions of the models above, illustrate Naylor et al.'s (1966) four rationale for the use of simulation experimentation:

1) For some processes, it is either too costly or impossible to obtain real world observations.

2) Through simulation, certain changes in a process or system, which would otherwise be impossible to accomplish, can be executed, and the effects of these changes on the system can be observed.

3) Simulation allows experimentation with complex interactions of a system or subsystem.

4) Simulation facilitates the examination of dynamic processes or systems over time by allowing the compression of real time.

The remaining sections of this chapter detail the research methodology for this study; i.e., how a simulation model of a physical distribution transportation system was constructed to aid in the investigation of the present research question.

**VARIABLE DEFINITIONS AND OPERATIONALIZATIONS**

Table 5 contains a listing of variables discussed below, along a description of each level and the procedures for determining operationalization of the variables.
DEPENDENT VARIABLE

A transaction, in the context of this study, was the shipment of a product from manufacturer to customer. The dependent or response variable in this study was the mean total (transaction plus production) cost of a shipment from manufacturer to customer. Each replication of the simulation model represented product shipments for one year (250 days), with actual model output being the total shipment cost averaged over one year, i.e., the mean shipment cost. The total cost of a product shipment consisted of the costs of each of the activities that occurred so that the shipment could be transported from manufacturer to customer. Delineation and representation of these activities and their costs are discussed in the section, NETWORK SIMULATION MODEL.

In general, costs for any one logistics function should generally be examined in consideration with total logistics system costs. However, transportation is a crucial logistics function due to the exceptional influence it exerts on other aspects of the total logistics system. Furthermore, almost one-quarter of the products transported in this country are transported by motor carrier, and expenditures on motor carrier transportation account for more than two-thirds of total transportation expenditures (Delaney 1986; Stern and El-Ansary 1988; Bardi and Tracey 1991). Because of the significant influence of motor carrier transportation costs, this study focused on transportation costs.

INDEPENDENT VARIABLES

Four independent variables were used to examine the present research problem: structure, asset specificity, uncertainty, and volume/frequency. The values used in the
<table>
<thead>
<tr>
<th>Variable</th>
<th>Operationalization/Measurement</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Total Shipment Cost(^1)</td>
<td>Total (transaction + production) Shipment Cost (mean for one year (250 days))</td>
<td></td>
</tr>
<tr>
<td>Structure(^2)</td>
<td>Relevant Shipment Costs</td>
<td>Level 1: Private/Leased Carrier (Sp)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level 2: Contract Carrier (Sc)</td>
</tr>
<tr>
<td>Asset Specificity(^3)</td>
<td>Type of Carrier</td>
<td>Level 1: Standard, Dry Freight Trailers (Al)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level 2: Refrigerated Trailers (Ah)</td>
</tr>
<tr>
<td>Uncertainty(^2)</td>
<td>Variation in Loading, Line-Haul Transportation Times</td>
<td>Level 1: Low (Ul)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Small Variation in Loading, Line Haul Transportation Times)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level 2: High (Uh)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Large Variation in Loading, Line Haul Transportation Times)</td>
</tr>
<tr>
<td>Volume/Frequency(^2)</td>
<td>Frequency of Shipments</td>
<td>Level 1: Low (VI)</td>
</tr>
<tr>
<td></td>
<td>Note: shipment size is held constant so that increased frequency of shipments is indicative of increased volume</td>
<td>(350 Shipments/year)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level 2: High (Vh)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1200 Shipments/year)</td>
</tr>
</tbody>
</table>

\(^1\) Dependent Variable

\(^2\) Independent Variable
operationalization of the two levels (low and high; see discussion below) of each independent variable were determined from several sources. The primary source was a series of interviews with the distribution manager of a manufacturer of industrial products (company H) whose transportation network provided the basis for the simulation model in this research. Additional sources included: a manufacturer of food products (company P) that require refrigerated transportation; the management of a third party logistics firm (company B) that company H contracts with to transport a portion of its shipments; and finally, information from Coyle, Bardi, and Cavinato (1990); Lambert and Stock (1982); and statistics complied by the American Trucking Associations (1992a, 1992b). Information gained from these sources, along with a series of pilot runs of the simulation model facilitated model operationalization, particularly for transaction costs levels. These pilot runs for the transportation simulation are somewhat comparable to pretesting for a laboratory experiment in order to establish construct validity of the independent variable manipulations. During pretesting for a laboratory experiment, some indication of the treatment level manipulations for a variable may be inferred from manipulations and effect sizes demonstrated in previous research (Sawyer and Ball 1981; Purdue and Summers 1986). However, since only three of the empirical TCA studies reviewed measured normative performance outcomes (see Table 4), and none used mean shipment cost as the dependent variable, it was impossible to ascertain even an estimate of the expected effect size and the manipulations required. The actual values used for the four independent variables are specified and discussed in CHAPTER IV.

The first independent variable, structure, refers to whether the transportation of a product is accomplished in carriers leased by the firm or in contract carriers, and consisted of two levels, internal and external. Structure was operationalized by application of the
appropriate costs, i.e., those costs which were incurred by the activities involved in a product shipment.

The second independent variable, asset specificity, refers to physical asset specificity and concerns whether the equipment used for transporting a product is redeployable to other activities. For example, if a product demands special handling during transportation, investment in specialized carrier equipment (e.g., refrigerated) is required. There were two levels of asset specificity represented in this research: low and high. Low asset specificity was operationalized as the dollar amount of investment in standard, dry freight trailers; high asset specificity was operationalized by the dollar amount of investment in refrigerated trailers.

Requirements for specialized carriers affect the cost of transportation in several ways. Where transportation is accomplished by a private fleet, transportation costs may be increased because of the higher capital investment or leasing expenses required for specialized carriers (Benson 1994). Furthermore, there tend to be fewer alternative suppliers of specialized carrier services. For example, the distribution of motor carriers included in the American Trucking Associations’ 1992 Motor Carrier Annual Report discloses that the proportion of refrigerated carriers included in the report was 6.6%, while carriers of general freight comprised 50% of carriers (American Trucking Associations 1992a).

In addition to actual "production" (loading and transportation) costs of transportation referenced above, indirect costs surrounding transportation activities increase when specialized carriers are required. This increase in indirect costs occurs because of increased negotiation costs:

where asset specificity is great, buyer [shipper] and seller [carrier] will make special efforts to design [i.e., negotiate] an exchange relationship . . ." (emphasis added) (Williamson 1981a, p. 1546).
Special efforts on the part of the shipping firm occur because there are fewer alternative suppliers of specialized transportation service. Special efforts on the part of the supplier of transportation service occur because of the firm’s requirements for an adequate return on investment in the required equipment (Cavinato 1984).

Uncertainty refers to how unpredictable the transportation activity is. As discussed in Chapter II (see Logistics Outsourcing Studies and Transportation Outsourcing Studies) in a logistics context, customer service requirements (e.g., order cycle time) are an important consideration. Events that increase the difficulties of maintaining customer service requirements are therefore significant decision factors in a logistics context. Given this study’s conceptual foundation (TCA), operationalization of this construct required a consideration of factors that had the potential for increasing the difficulty of monitoring and/or enforcing agreements (that increased transaction costs), especially when specific assets (refrigerated carriers) were required. Since this study focused on the transportation function, the portion of the order cycle that transportation is responsible for (loading and line haul transportation) was chosen as the focus for this factor. For this reason, uncertainty in this research was represented by operational uncertainty caused by events (e.g., weather or road conditions) that made it difficult to accomplish on-time delivery of shipments to customers. Operational uncertainty has the potential to increase transaction costs for either private/leased transportation or contract transportation. It may increase the number of contingencies that must be specified in a contract with a carrier, as well as making it more difficult to monitor compliance with customer service requirements (requirements for on-time delivery to the shipper’s customers) for either private/leased shipments or contract shipments. There were two levels of uncertainty in this study: low and high. Low operational uncertainty was represented by distributions for loading and line haul transportation durations which resulted in predictable (less variance in) product delivery
times; high operational uncertainty was represented by distributions for loading and line haul transportation durations which resulted in unpredictable (more variance in) product delivery times.

Volume/frequency consisted of two levels: low and high volume. The primary purpose of this TCA dimension was to illustrate the degree of asset utilization, and it essentially deals with the issue of scale economy. Was the volume of transportation activity that occurred in a particular type of carrier enough to justify the cost of the firm’s investment in that type of carrier? According to Williamson, “the cost of specialized governance structures [e.g., investment in transport equipment] will be easier to recover for large transactions of a recurring kind [e.g., frequent product shipments from manufacturer to customer]” (1985, p. 60). Therefore, in the context of this research, volume/frequency was operationalized as the frequency of shipments, i.e., the number of shipments per year shipped in a particular type of carrier (standard trailer or refrigerated trailer). In order to ensure that shipment frequency was, in fact, an indication of volume/frequency transported, shipment size was held constant (truckload (TL) shipments only), so that increased frequency of shipments was indicative of increased volume.

RESEARCH HYPOTHESES - RESEARCH DESIGN

This section examines how the variables discussed above were used to investigate the research questions stated in CHAPTER I. In order to answer these research questions, the hypotheses focused on the exploration of interaction effects, as well as the accompanying simple main effects, of the four independent variables of structure, asset specificity, uncertainty, and volume/frequency. The research design was chosen to facilitate this examination of the interactions and simple main effects. One objective of examining independent variables within the context of the experimental design of this
research was to explore the lack of results and/or the contradictory results of previous TCA studies.

RESEARCH HYPOTHESES

Interaction of Structure and Asset Specificity

Williamson's TCA framework contends that requirements for investment in specialized assets change the contracting relationship between a buyer and seller from one of "large numbers" bargaining to one of "small numbers" bargaining. Given the behavioral assumption of opportunism, the design and maintenance of such a relationship necessitates increased levels of contracting, monitoring, and enforcement activities in order to ensure reduced risks to both buyer and seller, that is: 1) continuation of service at a reasonable cost to the buyer and 2) continuation of demand for the service from the buyer in order that the seller recovers a reasonable return on the required asset investment (Williamson 1985).

The more specialized the type of transportation carrier, the fewer carriers exist (American Trucking Associations 1992a). The fact that fewer specialized carriers exist provides the possibility of a "small numbers" bargaining situation. Furthermore, the rates charged by those carriers frequently exceed the rates charged by the nonspecialized carriers because of discriminatory value-of-service pricing (Talley 1988). For carrier firms, investment in specialized (e.g., refrigerated) carriers requires assurance of a return on that investment, i.e., an investment "for which the net present value is positive" (Talley 1988, p. 26). The higher rates charged by carrier firms seeking to recover their investments, along with the transaction costs (negotiation costs) involved in contracting for transportation, suggest that when refrigerated carriers (Ah) are required, maintaining a private/leased carrier fleet (Sp) may be less costly than shipping in contract carriers (Sc).
On the other hand, when nonspecialized carriers, i.e., standard dry freight trailers (AI), are required for a product's transportation, maintenance of a private/leased fleet means that the shipping firm must make an investment (either through purchase or lease) in this equipment, when the service provided may be readily available, at a lower cost, without that investment.

Based on the discussion above, the first hypotheses predict that asset specificity will modify the main effect of structure on the response variable (mean shipment cost) (see Figure 3):

H1A Over all conditions of uncertainty and volume, the more efficient alternative (measured by mean shipment cost) for shipments requiring standard trailers (AI) will be contract carriers (Sc) (AI has a negative slope).

H1B Over all conditions of uncertainty and volume, the more efficient alternative (measured by mean shipment cost) for shipments requiring refrigerated trailers (Ah) will be private/leased carriers (Sp) (Ah has a positive slope).

Interaction of Structure and Uncertainty

According to Williamson (1975, 1985), when uncertainty exists, all alternative outcomes can neither be considered nor specified. Williamson contended that increasing uncertainty increases the number of contingencies that must be considered when attempting to forge and administer agreements between two parties for the performance of a function. As the number of contingencies increases, it becomes increasingly difficult to negotiate agreements, as well as to monitor and enforce existing agreements, potentially increasing the transaction costs when activities are performed externally. According to TCA however, uncertainty only increases transaction costs when specific assets are involved. If specific assets (e.g., refrigerated trailers) are not required

new trading relations can be easily arranged by both parties. Increasing the degree of uncertainty does not alter this (Williamson 1985, p. 79).
FIGURE 3  HYPOTHESES 1 - 6
In other words, unless specific asset requirements force the necessity for relatively long term agreements (to ensure that the required assets are available to the shipper, and that the carrier will receive an appropriate return on the asset investment), uncertainty will not increase transaction costs. Therefore, uncertainty should not modify the main effect of structure on the response variable (mean shipment cost), which means that the effect of structure on shipment cost should not vary according to the level of uncertainty.

Furthermore, since there are several higher order interactions predicted (see discussion below) involving factors (asset specificity and volume; see Table 4) that have been the source of significant findings in previous TCA research, significant differences between shipping in private/leased carriers (Sp) and contract carriers (Sc) may be masked for this first order interaction (see Figure 3).

H2: Over all conditions of asset specificity and volume, there will be no significant difference between the mean cost of shipments in private/leased carriers (Sp) and the mean cost of shipments in contract carriers (Sc); this will be true no matter what the level of operational uncertainty is (low (Ul) or high (Uh)) (both Ul and Uh have a slope of 0).

It should be noted that if environmental uncertainty (which requires a firm to maintain strategic flexibility) exists, this hypothesis would predict outsourcing (Sc), rather than private/leased fleet (Sp), to be the more efficient structure (see discussion of organizational, strategic management, and public policy research under Williamson).

Interaction of Structure and Volume/Frequency

Williamson’s (1979, 1985) explication of what he terms the transactional dimension of frequency (referred to in this research as volume/frequency or volume) serves the primary purpose of cost justification for a firm’s investment in the assets required for an activity. This means that the more fully utilized the assets required for transportation, the lower the cost of shipping a product (Talley 1988).
If the volume of shipments is low (VI), the shipper will not be able to realize economies of scale. In this situation, the firm is better off using contract carriers (Sc), who can aggregate shipments and realize scale economies.

However, if the volume of shipments is high (Vh), private/leased carriers may be the more efficient alternative (Sp). Due to the large volume transported in its equipment, the shipping firm will be able to realize economies of scale. In this case, shipping in contract carriers would be less efficient, since the total shipment cost would include any transaction costs incurred contracting, in addition to the rate charged by the carrier for the shipment.

Based on the discussion above, the third set of hypotheses predict that volume will modify the main effect of structure on the response variable (mean shipment cost) (see Figure 3):

H3A: Over all conditions of uncertainty and asset specificity, when the volume of shipments is low (VI), the more efficient alternative (measured by mean shipment cost) will be contract carriers (Sc) (VI has a negative slope).

H3B: Over all conditions of uncertainty and asset specificity, when the volume of shipments is high (Vh), the more efficient alternative (measured by mean shipment cost) will be private/leased carriers (Sp) (Vh has a positive slope).

**Interaction of Structure, Asset Specificity, and Uncertainty**

The interaction of structure and asset specificity will have differing effects on mean shipment cost, depending on whether operational uncertainty is low (UI) or high (Uh). TCA predicts that when both requirements for specific assets and uncertainty are present, the necessity for protection of the specific assets becomes critical. Uncertainty increases the chances for information asymmetries and opportunism on the part of both buyer and seller, causing an increase in the number of contingencies that must be specified and monitored in contracts between parties, and consequently, higher transaction costs (Williamson 1979, 1985).
Under conditions of low operational uncertainty (Ul), when shipments can go in standard trailers (Al), the cost of shipping in private/leased carriers (Sp) should be higher than the cost of contract carriers (Sc). However, when refrigerated carriers are required (Ah), private/leased carriers (Sp) are more efficient than contract carriers (Sc), because of the possibility of small numbers bargaining.

Under conditions of high operational uncertainty (Uh), when shipments can go in standard trailers (Al), contract carriers (Sc) are still the more efficient alternative. However, when the requirement for refrigerated trailers (Ah) is combined with high operational uncertainty (Uh), according to TCA it [is even] *more imperative* . . . to "work things out. Failure to support transaction-specific assets . . . results in costly haggling (emphasis added)" (Williamson 1985, p. 79).

Therefore, when a high degree of uncertainty (Uh) is combined with the requirement for refrigerated trailers (Ah), private/leased carriers are still the more efficient alternative, but contract carriers (Sc) are even more costly than they were under low operational uncertainty (Ul).

The following hypotheses predict that the pattern of the interaction of structure and asset specificity is modified by operational uncertainty (see Figure 3; H4A and H4B):

**H4A** Across all volume conditions, when operational uncertainty is low (Ul) and a shipment can go standard trailers (Al), the more efficient alternative (measured by mean shipment cost) will be contract carriers (Sc) (Al has a negative slope). However, if refrigerated trailers are required (Ah), the more efficient alternative will be private/leased carriers (Sp) (Ah has a positive slope).

**H4B** Across all volume conditions, when operational uncertainty is high (Uh) and a shipment can go in standard trailers (Al), the more efficient alternative (measured by mean shipment cost) will be contract carriers (Sc) (Al has a negative slope). However, if refrigerated trailers are required (Ah), the more efficient alternative will be private/leased carriers (Sp), and the difference (in mean shipment cost) between private/leased carriers (Sp) versus contract carriers (Sc) will be enhanced under high operational uncertainty (Uh).
Interaction of Structure, Asset Specificity, and Volume/Frequency

The effect of the interaction of structure and asset specificity on total shipment cost will differ, depending on the volume of product transported.

As H1 indicated, if a product can go in standard trailers (Ai), TCA predicts that shipping by contract carrier (Sc) will be more efficient (see Figure 3, H1A; slope of Ai is negative). When refrigerated trailers are required (Ah), transaction costs tend to increase (due to small numbers bargaining), as the parties seek to ensure either an adequate supply of refrigerated equipment or an adequate return on investment in refrigerated carriers. This means that shipping products requiring refrigerated trailers is more efficient in private/leased carriers (see Figure 3, H1B; slope of Ah is positive).

However, when the effects of different levels of shipment volume are considered, the transaction cost effects of asset specificity may be modified by the effects of economies of scale. If shipment volume is low (Vi) and shipments can go in standard trailers (Ai), the more efficient alternative is contract carriers (Sc). If shipment volume is low (Vi) and shipments require refrigerated trailers (Ah), the cost advantage of private/leased carriers (which was caused by the higher transaction costs for the contract carriers) may be reduced because of the scale economies enjoyed by contract carriers (Sc), making them the more efficient alternative.

If shipping volume is high (Vh), and shipments can go in standard trailers (Ai), the economies of scale generated by the higher volume will cause private/leased carriers (Sp) to be slightly more efficient. If shipment volume is high (Vh) and refrigerated trailers are required (Ah), the cost advantage of private/leased carriers (Sp) (because of lower
transaction costs), combined with the scale economies conferred by the higher volume of shipments, will make private/leased carriers (Sp) more efficient.

Based on the foregoing discussion, the next hypotheses predict that the pattern of the interaction of structure and asset specificity is modified by volume (see Figure 3, H5A and H5B):

**H5A:** Across all conditions of operational uncertainty, when the volume of shipments is low (Vl), the more efficient alternative (measured by mean shipment cost), for either shipments in standard trailers or shipments in refrigerated trailers (for either Al or Ah), will be contract carriers (Sc) (slopes of Al and Ah are negative).

**H5B:** Across all conditions of operational uncertainty, when the volume of shipments is high (Vh), the more efficient alternative (measured by mean shipment cost), for either shipments in standard trailers or shipments in refrigerated trailers (for either Al or Ah) will be private/leased carriers (Sp) (slopes of Al and Ah are positive).

**Interaction of Structure, Uncertainty, and Volume/Frequency**

Because TCA predicts that uncertainty has no effect unless it occurs in conjunction with high asset specificity requirements (Williamson 1985), there should be no interaction between structure, uncertainty and volume/frequency. That is, the combined effects of these three variables should exhibit a pattern identical to H3, the interaction of structure and volume. Under conditions of either low (Ul) or high (Uh) operational uncertainty, when shipment volume is low (Vl), the scale economies realized by combining volumes from several shippers will make contract carriers (Sc) the more efficient alternative. Under conditions of either low (Ul) or high (Uh) operational uncertainty, when shipment volume is high (Vh), scale economies realized by the shipping firm make private/leased carriers (Sp) the more efficient alternative.

Based on the discussion above, the next hypotheses predict (see Figure 3):
H6A: Across all asset specificity conditions, when operational uncertainty is low (Ul) and shipment volume is low (Vl), contract carriers (Sc) are the more efficient alternative (measured by mean shipment cost) (slope of Vl is negative). However, if shipment volume is high (Vh), private/leased carriers (Sc) are the more efficient alternative (slope of Vh is positive).

H6B: Across all asset specificity conditions, when operational uncertainty is high (Uh), and shipment volume is low (Vl), contract carriers (Sc) are the more efficient alternative (measured by mean shipment cost) (slope of Vl is negative). However, if shipment volume is high (Vh), private/leased carriers (Sp) are the more efficient alternative (slope of Vh is positive; identical pattern to H6A).

Interaction of Structure, Asset Specificity, Uncertainty, and Volume/Frequency

The interaction of structure, uncertainty, and volume will have differing effects on mean total shipment cost, depending on the level of uncertainty.

Adding a high degree of uncertainty to a situation where specialized assets are required, in Williamson's words "makes it more imperative to 'work things out'" (emphasis added) (1985, p. 79). Therefore, under conditions of high operational uncertainty (Uh), when refrigerated trailers (Ah) are required, transaction costs will be higher than when operational uncertainty is low (Ul). When volume shipped is low (Vl), these higher transaction costs (resulting from the combined effects of asset specificity (Ah) and uncertainty (Uh)), will, to some extent, offset the cost advantage of shipping in contract carriers (Sc). On the other hand, when a high volume (Vh) is shipped in refrigerated trailers (Ah), making private carriers (Sp) the more efficient alternative (refer to H5A and H5B), the higher transaction costs resulting from the combined effects of asset specificity (refrigerated trailers, Ah) and operational uncertainty (Uh), will make contract carriers (Sc) even more expensive than under conditions of low operational uncertainty.

The final set of hypotheses predicts (see Figure 4):

H7A: Under either low (Ul) or high (Uh) operational uncertainty, when shipment volume is low (Vl), and refrigerated trailers are required (Ah), contract...
carriers (Sc) are the more efficient alternative (measured by mean shipment cost); however, high operational uncertainty (Uh) will diminish the difference between the mean shipment cost for contract (Sc) versus private/leased (Sp) carriers (slope of Ah is less negative in graph (II) than graph (I) of Figure 4).

When shipments go in standard trailers (Al), high operational uncertainty (Uh) causes no diminishment in the difference (in mean shipment cost) for contract (Sc) versus private/leased carriers (Sp) (slope of Al is the same for graphs (I) and (II) of Figure 4).

H7B: Under either low (Ul) or high (Uh) operational uncertainty, when shipment volume is high (Vh), and refrigerated trailers are required (Ah), private/leased carriers (Sp) are the more efficient alternative (measured by mean shipment cost); however, under high operational uncertainty (Uh), this effect will be enhanced, magnifying the difference (in mean shipment cost) for private/leased (Sp) versus contract (Sc) carriers (slope of Ah is more positive for graph (IV) than graph (III) of Figure 4).

When shipments go in standard trailers (Al), high operational uncertainty (Uh) causes no enhancement in the difference (in mean shipment cost) for contract (Sc) versus private/leased (Sp) carriers (slope of Al is the same for graphs (III) and (IV) of Figure 4).

Research Design

In order to fully explore the interactions and simple main effects among the independent variables suggested by TCA and predicted by the hypotheses above, a full factorial design was used. The design consisted of four factors (structure, asset specificity, uncertainty, and volume). Each factor had two levels, resulting in a $2^4$ design, with 16 cells. Table 6 represents the factorial structure, and Table 7 contains the design matrix, illustrating factor level combination for each of the 16 cells of the design. Analysis of variance was used to examine the output from the experimental manipulations of the simulation model.

The use of analysis of variance depends on the following assumptions about the sample observations and the populations from which these observations originate:

1) Sample observations are assumed to be independent of each other.
FIGURE 4  HYPOTHESES 7A AND 7B
2) Sample observations are assumed to originate from a normal population.

3) The variances of the populations are assumed equal.

The use of a simulation model to perform experiments introduces several distinguishing features which impact on the assumptions implicit in the use of analysis of variance. Simulation allows a high degree of control over the experimental conditions, even to the point of controlling factors which would be uncontrollable in the actual system of interest (Law and Kelton 1982). Furthermore, the "deterministic nature of random-number generators" used in a simulation allows the researcher to "control the basic randomness in the experiment" (Law and Kelton 1982, p. 372), thereby eliminating the need for random assignment to cells to protect against systematic variation. In a simulation, experimental error is introduced by the model's random number generators, instead of by the uncontrollable and/or unobserved factors that occur in the "real world" (Kleijnen 1975).

Regarding the independence assumption, if samples are generated from independent replications of simulation runs (i.e., the random number streams used in successive simulation replications are independent), the analysis of variance assumption of independence is met (Fishman and Kiviat 1968; Kleijnen 1974). Finally, if each cell has an equal number of observations, then even in the presence of a relatively small number of degrees of freedom (small sample size), the F-test used in analysis of variance is relatively insensitive both to departures from normality and unequal variances (Ott 1988; Schefte 1959). For this reason, the number of replications (the sample size) for each of the 16 cells in the experimental design was equal.

The following model was assumed to represent the effects of the independent variables and their interactions on the dependent variable:

\[ Y_{ijklm} = \mu + \xi_i + \eta_j + \iota_k + \tau_l + (SA)_{ij} + (SU)_{ik} + (SV)_{il} + \\
(SAU)_{ijk} + (SAV)_{ijl} + (SUV)_{ikl} + (SAUV)_{ijkl} + \epsilon_{ijklm} \]
<table>
<thead>
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<th>Nonspecific</th>
<th>Asset Specificity</th>
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### Table 6

**Factorial Structure**

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### TABLE 7  
**DESIGN MATRIX FOR 2^4 FACTORIAL DESIGN**

<table>
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<tr>
<th>Cell #</th>
<th>Factor 1: Structure&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Factor 2: Asset Specificity&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Factor 3: Uncertainty&lt;sup&gt;3&lt;/sup&gt;</th>
<th>Factor 4: Volume/Frequency&lt;sup&gt;4&lt;/sup&gt;</th>
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1 = Level 1/Low  
2 = Level 2/High

<sup>1</sup> Level 1 = Internal (transportation by private/leased fleet; Sp)  
Level 2 = External (transportation by contract carrier, Sc)

<sup>2</sup> Level 1 = Low Asset Specificity (Al)  
Level 2 = High Asset Specificity (Ah)

<sup>3</sup> Level 1 = Low Uncertainty (Ul)  
Level 2 = High Uncertainty (Uh)

<sup>4</sup> Level 1 = Low Volume/Frequency (Vl)  
Level 2 = High Volume/Frequency (Vh)

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Where:

\( Y_{iklm} \) is the total cost for a product transported using

the \( i^{th} \) Structure level,

the \( j^{th} \) Asset specificity level,

the \( k^{th} \) Uncertainty level,

the \( l^{th} \) Volume/Frequency level, and

the \( m^{th} \) replication of the simulation.

\( S \)

is the effect of Structure; \( i = 1,2 \)

\( A \)

is the effect of Asset Specificity; \( j = 1,2 \)

\( U \)

is the effect of Uncertainty; \( k = 1,2 \)

\( V \)

is the effect of Volume/Frequency ; \( l = 1,2 \)

\( \mu \)

is the overall mean

\( \epsilon_{iklm} \)

is the variation in \( Y \) not explained by the model

\( m \)

identifies the replication number of the simulation

The research hypotheses discussed above predicted a number of significant first, second and third order way interactions (SA, SU, SV, SAU, SAV, SUV, and SAUV). In addition, a number of simple main effects were hypothesized. Analysis of variance was used to test the model's main effects and the hypothesized interactions. Either Scheffe's or Fisher's LSD test (depending on how many cell means were being compared (Ott 1988)) was used to test the hypothesized comparisons.

**NETWORK SIMULATION MODEL**

This portion of the chapter describes the simulation model used to investigate the research questions examined in this study. The following section discusses how the model was constructed and the model parameters. The third section addresses validation of the
model. The fourth section examines some aspects of simulation performance that impact on
the accuracy and reliability of estimates of system response (mean total shipment cost).

MODEL CONSTRUCTION AND MODEL PARAMETERS

The transportation network model used in this study was a dynamic simulation
constructed with the SLAM SYSTEM simulation software package, which uses SLAM II
simulation language. SLAM II is a FORTRAN based simulation language which permits the
construction of a network model capable of simulating discrete event, and/or continuous
systems (Pritsker 1986; Pritsker, Sigal, and Hammesfahr 1989). Constructing a simulation
model using SLAM II consists of combining specialized symbols "into a network model
which pictorially represents the events and processes of the system of interest" (Pritsker
1986, p. 63).

The transportation model used in this research was a process model with a network
structure consisting of nodes and branches. A node represented the beginning or end of an
activity; a branch represented the process of an ongoing activity. Stochastic product
demand generated shipping orders, and shipments were loaded and transported (using either
private/leased carriers or contract carriers). If transportation was outsourced, it was
assumed that the shipping firm paid all loading and transport costs. Transportation activities
consisted of carrier selection; contract negotiation; compilation and review of transportation
reports (e.g., customer service reports); and auditing and payment of freight bills. If
transportation was accomplished by the firm’s private/leased fleet, fleet management
operations (e.g., freight routing and tracking; renewal of equipment leases; payroll activities;
compliance with ICC and/or DCT regulations) were performed; and transportation reports
(e.g., customer service reports) were compiled. As a shipment was loaded and transported,
costs accumulated for the activities performed. The total cost of the shipment consisted of
these accumulated costs. The effect on the response variable (total shipment cost) to manipulations of the independent variables of structure, asset specificity, uncertainty, and volume/frequency was explored using the research design described in the previous section.

The design of the transportation activity cost parameters in this model were derived from four sources. The first is Talley's (1988) Transport Carrier Costing. The second was a series of articles in Accountancy and Management Accounting, which contained discussions and applications of Activity Based Costing. The third source, which largely determined the actual values, was a series of interviews with three organizations: 1) the distribution manager of a firm that manufactures and distributes industrial products (referred to hereafter as company H); 2) the inventory planning and control manager of a manufacturer of food products that require refrigerated transportation to grocery retailers (referred to hereafter as company P); and 3) the management of the logistics firm (referred to hereafter as company B) that company H contracts with to transport a portion of its finished products. The fourth and final group of sources, which also helped determine the actual values for shipment costs, was information from Coyle, Bardi, and Cavinato (1990); Lambert and Stock (1982); and the American Trucking Associations (1992a, 1992b).

In Transport Carrier Costing, Talley (1988) presented detailed descriptions of transportation activities, resources used in those activities, cost drivers of those activities, relationships between transportation activities and cost drivers, and transport carrier pricing procedures. Talley's explication of specific transportation activities was the basis for the loading and line haul transportation activity designations in the model (see Activity Based Costs for the Transportation Network Model, below).

Activity Based Costing (ABC), discussed in a series of articles in the journals of Accountancy and Management Accounting, is an alternative to traditional cost accounting procedures. ABC seeks to "identify cost drivers, [and] establish driver-cost relationships"
(Roth and Borthick 1991, p. 39). The purpose of ABC is to more closely tie costs incurred with the activities that are responsible for the costs, and to reduce arbitrary allocation of indirect costs. By: 1) identifying activities and the cost drivers of those activities, and 2) explicating the relationship between an activity and its cost drivers, ABC has the potential to improve management decision making ability (Lewis 1991; Roth and Borthick 1991; Cooper 1991). ABC was used as the basis for the per shipment assignment of costs for some of the transportation activities in the model.

Information gained from the interviews referred to above, combined with details from Coyle, Bardi, and Cavinato (1990); Lambert and Stock (1982); and the American Trucking Associations (1992a, 1992b), served two purposes. During the construction of the network simulation model, these sources helped ensure that the model elements represented as closely as possible the process they were meant to depict, that is, they were used to enhance the face validity of the model. Once the model was constructed, cost data provided by the company H were used as part of the model validation procedures (this is discussed in more detail in the MODEL VALIDATION section, below).

**Activity Based Costs for the Transportation Network Model**

The total shipment cost for products shipped by the model’s leased carrier fleet was composed of fixed and variable direct and indirect costs of transportation activities. Transportation activities which incurred direct costs were loading and line haul transportation.

Direct costs of loading consisted of labor costs. The cost driver for the pickup activity was the volume loaded, indicated in the model by the number of labor hours required to load the shipment. Direct costs of line haul included a "fixed" portion, i.e., the investment in carrier equipment expended (in this case, leasing expenses) as well as taxes,
license fees, maintenance, and insurance costs incurred for that equipment, plus a "variable" portion, consisting of fuel, maintenance, and labor expenses. The cost driver for the fixed portion of line haul transportation costs was the number of shipments; the cost driver for the variable portion was miles driven. Indirect costs of a product shipment consisted of clerical/management salaries for fleet management activities, tracing shipments, and monitoring customer service outcomes. The cost driver for these indirect transportation costs was the number of shipments.

If the firm did not perform the transportation function internally, but instead outsourced the shipment, the shipment cost consisted of the rate charged by the carrier firm, plus the indirect costs, i.e., the "costs of bargaining, assembling information, monitoring compliance" (John 1984, p. 279), associated with the activities involved in contracting for transportation services. These indirect costs involved management/staff salaries devoted to: formulating the contracts between the shipper and the carrier, selecting the most competitive rate for a shipment, ensuring the carrier firm’s accomplishment of the required service (e.g., customer service requirements), and auditing and preparing freight payments.

The rate the carrier firm charges for transporting a product is determined by the carrier firm’s cost structure and its desired profit margin. According to Talley (1988), carrier firms frequently use a pricing practice known as discriminatory value-of-service pricing, which is

the practice of . . . charging commodities with relatively price inelastic transportation demands higher prices than those commodities with relatively price elastic transportation demands (p. 24).

One of the primary reasons for price inelastic transportation demand is a relative scarcity of alternative suppliers for a particular transportation service. The fact that there are fewer suppliers possessing refrigerated trailers (American Trucking Associations 1992b) could be
an indication of Williamson's (1985) "small numbers" bargaining situation in the face of specific asset requirements.

**MODEL VALIDATION**

In his discussion of a simulation model's formulation and subsequent validation, Pritsker (1986) maintained that

the actual process of formulating the model is largely an art. The modeler must . . . be able to extract the essence of the system without including unnecessary detail. . . . The amount of detail included in the model should be based on the purpose for which the model is being built. Only those elements which cause significant differences in decision-making need be considered (p. 11-12).

Further description of the validation process is offered by Law and Kelton (1982), who defined two primary processes involved in model validation. According to their definitions, *verification* consists of making sure the simulation model is executing as the modeler directed, while *validation* requires confirmation that the simulation model is an accurate representation of the system being modeled.

**Verification**

Law and Kelton (1982) discussed a number of techniques which may be used alone, or in combination, for model verification. Three of these techniques were employed to verify the transportation network model in this study.

The first technique deals with model construction. According to Law and Kelton (1982),

it is always better to start with a simple model which is gradually made as complex as needed, than to develop "immediately" a complex model, which may turn out to be more detailed than necessary (p. 334).

The construction of the transportation network model began with modules containing one or two of the activities involved in product transportation. The execution of these modules
was verified by the use of deterministic (rather than probabilistic) activities prior to combining the modules into a larger model.

The second technique, known as a *trace*, was used to verify the model during the later stages of model construction, once the activity modules had been combined. The trace provided "snapshots" of the system as it performed. This enabled evaluation of the path of the shipments in the system, as well as evaluation of the statistical counters (which accumulated shipment costs) so that it could be determined whether or not the model was executing correctly (Pritsker 1986; Law and Kelton 1982).

The third technique concerns verification of the uniformity and independence properties of the random number generators used to represent the stochastic elements of the model. Law and Kelton (1982) recommended several linear congruential random number generators (LCG), which have been shown to display sufficient uniformity and independence properties, and maintained that the uniformity and independence properties of these "good" LCGs can be presumed to be satisfactory. Since one of these, Schrage's portable FORTRAN random number generator, is included in the SLAM II simulation software package (Pritsker 1986), the uniformity and independence of the random number streams generated for the model constructed for this study were not explicitly tested.

**Validation**

Naylor and Finger (1967), citing Popper, maintained that, although complete validation of a model is never possible, one may arrive at "gradually increasing confirmation" (p. B-93) with regard to how well the model represents the system of interest.

Using this three-step approach to model validation, the paragraphs below describe the procedures that were used to validate the transportation network model in this study.

Law and Kelton’s (1982) first recommendation for model validation was that the modeler “develop a model with high face validity, i.e., a model which, on the surface, seems reasonable to people who are knowledgeable about the system under study” (p. 338). Suggestions for implementing this validation step included conversations with people familiar with the system being modeled; general knowledge gained from other models similar to the system under study (Law and Kelton); and formulation of a set of assumptions which specify the elements of the system and the relationships among them, i.e., tentative "hypotheses describing the behavior of the system" (Naylor and Finger 1967, p. B-95).

In order to construct a transportation network model that was high in face validity, the following procedures were followed. General knowledge about transportation systems was obtained from the review of logistics literature (in CHAPTER II) and the methodological review of distribution system simulation models in the first section of this chapter. Specific information about the transportation system of company H was acquired from the interviews discussed earlier in this chapter (see MODEL CONSTRUCTION AND MODEL PARAMETERS). The general knowledge was combined with specific information from the interviews to form assumptions about the model’s components and the relationships among them.

Law and Kelton’s recommendation for the second step of model validation concerned testing the assumptions (discussed in the previous paragraph), which were made during model construction. Van Horn (1969), Naylor and Finger (1967), and Law and Kelton (1982) recommended that one particularly useful technique for testing model assumptions is sensitivity analysis, e.g., testing how sensitive the model output is to changes in the distributions of the model’s stochastic elements. Sensitivity analysis on the
transportation model was accomplished by performing both graphical analysis and
significance testing.

Assumptions regarding model distributions which were likely to have the most
significant effects on the response variable were tested by changing the form of these
distributions (e.g., from triangular to uniform). Changes in the response variable were
examined graphically, as well as with t-tests (see CHAPTER IV for discussion of results).

The third step of model validation concerns comparison of model output results with
historical outputs from the real system under study. This step is essentially a test of the
model's ability to predict the behavior of the system of interest (Law and Kelton 1982;
Naylor and Finger 1967). There are a number of statistical techniques available for
comparison of actual and simulated system outputs, but, guided by Van Horn's (1969)
recommendation that "often simple comparisons of means, ranges, variances, and graphical
comparison of distribution or time behavior will capture most of the available information"
(p. 240), two techniques were used for the third validation step in this study.

The historical (i.e., actual) data for this validation step was supplied by company H.
Data from the company was particularly relevant to this research question because, over the
course of the last nine years, the company has restructured their transportation from
internal (leased fleet) to primarily external (contract). The first technique for this third step
of model validation consisted of graphs of the differences between the means of the actual
and simulated system response. The second technique (described by Law and Kelton 1982)
involved the computation of confidence intervals for the difference between the means of
actual and simulated system response. These confidence intervals provided information on
whether the differences in the means were statistically, as well as practically, significant
within the context of the system of interest.
SIMULATION

This section discusses several issues involved in assessing the performance (i.e., the accuracy and the reliability) of the simulation data used to investigate the research questions in this study. These performance issues are related to the two basic objectives of experimental design: 1) the elimination of systematic bias in the estimation of population parameters, and 2) the reduction of error (i.e., reduction of variance) (Stevens 1992). The following discussion (Truncation Procedures and Determination of Steady-State) examines the reduction of bias, and the final portion of this section (Stochastic Convergence, Sample Size, and Variance Reduction Techniques) discusses variance reduction.

Truncation Procedures and Determination of Steady-State

The research problem under consideration in this study required the comparison of the steady-state mean total shipment cost for various combinations of system factors (e.g., structure, asset specificity, uncertainty, and volume). Therefore, the determination of how long after initialization the simulation achieved steady-state conditions was an important issue. According to Pritsker (1986),

steady state behavior does not denote a lack of variability in the simulation response, but specifies that the probability mechanism describing this variability is unchanging and is no longer affected by the starting condition (p. 43).

Once the point at which the system achieves steady-state is determined, all sample values collected prior to that point can be discarded to reduce the bias of the estimations caused by the initial conditions of the simulation model. Although a number of authors have attempted to formalize rules for determining which values should be discarded (truncation rules (Wilson and Pritsker 1978, Pritsker 1986)) maintained that the most common approach is to graph the distribution of the simulation response during a series of pilot runs.
Observation of the point at which increases or decreases in the mean response cease, and/or the point at which the variance in the response stabilizes, identifies when sample data collection should begin. This was the procedure employed in the determination of steady-state conditions for the simulation model in this study.

**Stochastic Convergence, Variance Reduction Techniques, and Sample Size**

These three topics are discussed together because it is difficult to consider any one of them without consideration of the other two. In addition, they all address the issue of the precision of the estimate of a dependent variable (in this case mean total shipment cost). Precision of these estimates is important for this study because of its impact on the probability of detecting significant results for the proposed hypotheses, i.e., the power of the statistical tests of the proposed hypotheses. Reducing within group variability (the standard deviation within each cell) so that an experimental design is rendered more sensitive is one of the ways of increasing power. For this reason, power is “heavily dependent on sample size” (Stevens 1992, p. 174). Each of the topics discussed in this section addresses the issue of how to increase the precision (decrease the standard deviation) of the estimate of mean total shipment cost for each cell in the experimental design in this study.

*Stochastic convergence* can be described as the increased precision in population estimates obtained through increased sample size (Naylor 1971). In order to fulfill the research objectives of this study, sample means of total shipment cost obtained through simulation replications of the transportation system were used to estimate the population means of total shipment cost. Increasing the sample size decreases the standard deviation of a sampling distribution, thereby increasing the precision of the estimate of mean total shipment cost.
However, since the standard deviation of the sampling distribution is \( \sigma \sqrt{n} \), "to decrease the random error [i.e., increase the precision of the population estimate] by a factor of ten, one must increase the sample size by a factor of one-hundred" (Naylor 1971, p. 25). Therefore, the required increase in sample size may be precluded by time or cost considerations. An alternative to increasing the sample size is a set of procedures known as variance reduction techniques (VRT). These techniques reduce the standard deviation of the sampling distribution through the use of alternative experimental sampling conditions.

Law and Kelton (1982) indicated that the most frequently used and effective VRT involves the use of common random numbers. To implement this technique, simulations of alternative system conditions (cells) are initiated using the same random number seed (starting value), resulting in common random number streams across experimental conditions (Pritsker 1986). This technique requires that the random number stream generated for a particular purpose in one cell is generated for the same purpose in all other cells; this process is similar to blocking, or using the same subjects across cells to reduce variance (Law and Kelton 1982). A complication occurs with the use of common random numbers, in that this VRT produces observations which violate the independence assumption implicit in analysis of variance. Therefore, the procedures used to analyze sample data obtained from the simulations must be modified (Kleijnen 1974), and the consequences of this violation of the independence assumption must be weighed against the cost of increasing sample size.

Before addressing how these two issues (stochastic convergence and variance reduction) were dealt with in this study, the issue of sample size must be examined. There are three methods for adjusting the sample size, \( n \), in simulation studies: 1) simulation runs for each experimental condition (each cell) may be replicated \( n \) times, 2) observations of \( n \) subintervals of a simulation run may be increased by decreasing the length of the
subintervals, or 3) the simulation run may be continued for a longer period of time (Kleijnen 1974; Pritsker 1986). Kleijnen recommended replication of simulation runs (see 1, above) as the most desirable means of increasing sample size. His reasons for this recommendation are: 1) if VRT (e.g., common random number streams) are used, replication facilitates their application, and 2) replication, as opposed to subintervals or continuation of a simulation run, avoids the problem of autocorrelation (lack of independence) among observations. Following Kleijnen's recommendation, replication of simulation runs was used in this study to achieve the desired sample size.

As the discussions of stochastic convergence and VRT have demonstrated, determination of sample size is driven by the desired magnitude of $\sigma\sqrt{n}$ (i.e., the desired precision of population estimates), along with whether or not VRT are employed (with the possible compromise of sample independence).

The determination of the sample size required for the desired level of precision in this study was accomplished using a method adapted from Law and Kelton (1982), which assumes that the output from the simulation replications is a series of independent and identically distributed, but not necessarily normal, random variables. Law and Kelton detailed a "sequential procedure . . . for constructing a confidence interval with a specified relative precision" (p. 292). They differentiated between absolute precision (designated as $\beta$) and relative precision (designated as $\gamma$).

. . . [T]he actual confidence-interval half-length is the absolute precision of the confidence interval and . . . the ratio of the confidence-interval half-length to the magnitude of the point estimator [the sample mean] is the relative precision of the confidence-interval (p. 291).

In a further clarification of relative precision, Law and Kelton pointed out that, although not strictly correct, one can think of the relative precision as the 'proportion' of $\mu$ (population mean) by which $\bar{X}(n)$ (sample mean) differs from $\mu$ (p. 291).
The procedure consists of choosing an initial sample size \((n_0)\) and a target value for the relative precision \((\gamma)\). A series of pilot runs is conducted, replacing the sample size by \(n + 1\) for each successive pilot run, until the desired relative precision is attained. Based on a series of simulations for which the true value of \(\mu\) was known, Law and Kelton maintained that if the value of \(\gamma\) is sufficiently close to 0 \((\gamma \leq 0.15)\), and \(n_0 \geq 10\), the resulting confidence intervals will contain \(\mu\) at least 86.4% of the time.

Following Law and Kelton’s example, the target value in this study for relative precision was 5%, and the initial sample size was ten \((\gamma = 0.05; n_0 = 10)\). Note that in the discussion of distribution system simulation models at the beginning of this chapter, Karrenbauer used \(n = 5\), i.e., five replications per cell (see KARRENBAUER MODEL), but Gomes found that the number of replications needed to produce the desired precision was ten \((n = 10)\) (see GOMES MODEL).

Following the initial pilot run, the mean \((\overline{x}_{10})\) and variance \((s^2_{110})\) was computed, along with an estimate of the half-width of the (90%) confidence interval \((\delta_{(n,n)})\), using the following formula:

\[
\delta_{(10,10)} = t_{1.1-0.10/2} \sqrt{s^2_{110}/10}.
\]

If \(\delta_{(n,n)}/\overline{x}_{(n)} \leq \gamma\), that is, if \(\delta_{(10,10)}/\overline{x}(n) \leq 0.05\), then \(n = 10\) was sufficient for the specified degree of precision; if not, the sample size for the next sequence of pilot runs was increased by one, and the sample mean, variance, interval half-width, and \(\gamma\) were recalculated. This sequential procedure was followed until the sample size for the desired precision, over all experimental conditions, was ascertained.

As the earlier discussion of VRT indicated, it is possible that the number of replications required to achieve the desired precision could be reduced by VRT (e.g., common random numbers). However, since the use of common random number VRT
violates the independence assumption of analysis of variance (perhaps making alternative data analysis techniques necessary), the preferred procedure for this research was to increase reliability of the simulation data by increasing sample size, rather than resorting to the use of VRT.
CHAPTER IV
MODEL OPERATIONALIZATION AND ANALYSIS OF RESULTS

This chapter presents the details of the transportation model's operationalization and validation, as well as the results of the statistical analyses of the dependent variable (mean total shipment cost) in response to the manipulations of the experimental design. The chapter consists of five sections. The first section describes the outbound transportation system that was modeled. The second section details the model's operationalization by describing the components of the model and delineating how the independent variables were operationalized to investigate the research hypotheses. The third section discusses investigation of the model's operation prior to initiating the proposed experiments. This investigation included examination of the model for any bias created by initial conditions (steady state behavior); model verification and validation; and determination of the sample size required for the desired relative precision. The fourth section presents the results of the analyses which investigated the seven sets of hypotheses. The fifth section summarizes the principal findings of the analyses.

DESCRIPTION OF THE TRANSPORTATION SYSTEM

The model constructed for this research represented the truckload (TL) portion of the outbound transportation system of company H. This company manufactures industrial products and distributes them primarily to contractors at job sites. Product shipments originate from two manufacturing sites (C and M) located in the southeastern region of the US. Shipments are transported to every state in the US. Destinations for shipments can be grouped into four regions (NE, S, SW, W). The proportion of shipments going to each region is: NE, 40%; S, 20%; SW, 10%, W, 30%. The company ships approximately 350
TL shipments per year. Approximately 70% of these shipments originating from the M
manufacturing site, and the rest from the C manufacturing site.

The products that company H ships do not require specialized trailers for
transportation; they are shipped in standard, dry freight 48 or 53 foot trailers. The company
assumes responsibility for all loading and transportation costs; the customer at the
shipment’s destination is responsible for unloading the shipment. Claims for loss or damage
are settled between the customer and company H (if the shipment was transported by one
of the company’s leased carriers) or between the customer and the carrier firm (if the
product was shipped by contract carrier).

Presently, approximately 30% of the TL shipments from both manufacturing sites
are transported in company H’s leased carrier fleet ("private/leased carriers"); approximately
60% are transported by a single carrier firm ("third-party" shipments); and the rest are
transported by national TL carrier firms that company H contracts with on a year to year
basis ("contract carriers"). As the leases on its equipment expire, company H is not
renewing them. The company is also not renewing many of its contracts with TL carrier
firms. By the end of 1994, they expect that all of their TL shipments will be handled by one
carrier firm, i.e., a third party logistics company (either company B, or another company, if
their price and service are more competitive). There appear to be three primary reasons
cited for this change in the company’s transportation operations. The first reason concerns
liability issues inherent in private fleet operations. The company is self-insured and feels
that maintaining a private fleet exposes it to undue risk. The second reason pertains to the
noncompetitiveness of private fleet per mile costs due to empty backhauls. The company
does not want to invest the resources necessary to try to eliminate these empty miles. The
third reason has to do with the company’s perception of the disparity between the amount
of time spent on managing their private fleet (or, alternatively, managing contracting
activities with national TL carrier firms) and the amount of time spent managing transportation that is accomplished by a single carrier firm ("third party" shipments).

Managing the private fleet can be time consuming for several reasons. Among these are the necessity to conform to DOT and/or ICC regulations, labor union problems with drivers, and tracing delayed shipments. On the other hand, managing transportation for shipments transported by national TL contract carriers is time consuming because of the amount of time required to obtain information on carriers’ service records, their financial status, and how competitive their rates are. In addition, the bills received from contract carrier firms must be audited (e.g., the invoice from the carrier firm must have the certified bill of lading attached). Contrast these two scenarios (private fleet transportation and national TL contract carrier transportation) with the situation that is faced when all shipments are transported by a single carrier firm. There are no fleet operations activities, information gathering activities are reduced (contracting is done with only one firm), and there is no necessity for freight auditing (this is done by the "third party" carrier). A similar perception was echoed by the inventory control manager at company P, which manufactures grocery products. Managers at both companies maintained that redirecting management resources from fleet operations (or the management of contracting activities with multiple TL carriers) to managing the relationship with relatively few (or only one) carrier left time and resources available for activities that had a more positive strategic impact on the company (e.g., managing/monitoring customer service outcomes; redesigning distribution systems) (Peterson 1994a; Stewart 1993, 1994a, 1994b, 1994c, 1994d).

The next section of this chapter describes the transportation model and details the model’s operationalization.
MODEL OPERATIONALIZATION

DESCRIPTION OF MODEL COMPONENTS

The simulation model constructed for this research was a network model consisting of nodes and branches, with a node representing the beginning or end of an activity, and a branch representing the process of an ongoing activity. Figure 5, which is a graphical representation of the model, demonstrates the activities of each shipment that is transported through the network. These activities are described below.

Shipments originate at the CREATE node. At the CM node, shipments are assigned to originate from either the C or the M manufacturing facility. This designation (C or M) persists throughout the "life" of the shipment. The reason for this is that loading and transport durations, transport distances, and per mile freight rates differ depending on the manufacturing facility from which a shipment originates. These values (duration, distance, per mile rate) are needed later in the network for the computation of "production" costs (loading plus transportation costs). In addition to the C or M designation, the CM node specifies the costs of most of the indirect (transaction) activities (e.g., fleet management operations, customer service monitoring, contracting, and billing).

The next three sets of nodes (CDUR, MDUR; CRATE, MRATE; and CMILE, MMILE) assign the appropriate (C or M) DURATION (in days) to loading and transportation; the appropriate per mile freight RATE (C or M) for contract shipments; and the appropriate distance in MILES (C or M) to the four regional transportation routes (NE, S, SW, W).

Following the CMILE and MMILE nodes, the network splits into two separate networks. The path labeled Sp designates shipments that are transported by private/leased equipment. The path labeled Sc designates shipments that are transported by either national contract TL carriers, or alternatively, a single third party logistics provider. For the purposes of the
Figure 5: TRANSPORTATION NETWORK MODEL

- TRANSACTION COSTS ACCUMULATED
- TOTAL SHIPMENT COSTS
- CONTRACT NETWORK
- REGIONAL TRANSPORTATION ROUTES
- B.W., SW.
- EMPTY BAKICLES ASSEMBLED
- REGIONAL BAKILES ASSEMBLED
- COSTS AND PROPORTION OF
- COMMISSION
- CRATE
- CAR
- TRANSPORTATION DURATION AND
- PER MILE VALUES-derived

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experimental design and hypothesis testing, the Sc (contract) condition represented shipments transported by TL contract carriers. Simulation of shipments transported by a single carrier firm was used for model validation, and to investigate the relative cost among the three alternatives (Sp, Sc/CONTRACT, and Sc/THIRD PARTY). A discussion and results of the investigation of these three alternatives (Sp, Sc/CONTRACT, and Sc/THIRD PARTY) appears in CHAPTER V.

The network that extends from the path labeled Sp models the activities involved in private/leased fleet transportation. The node labeled BACKHAUL assigns each shipment passing through it a designation of either "empty" or "full," denoting whether or not the outbound shipment must be assigned the cost of an empty backhaul (essentially doubling the cost of the shipment (Coyle, Bardi, and Cavinato 1990)). Shipments are directed to the next two nodes, EMPTY or FULL, on the basis of the designation received at the BACKHAUL node. The EMPTY and FULL nodes assign per mile and per shipment leased equipment costs for the appropriate backhaul designation (for EMPTY shipments, both the per mile and the per shipment leased equipment costs are twice those of FULL shipments).

Following the assignment of the EMPTY or FULL equipment costs, all shipments traverse the activity labeled LOAD. Following the LOAD activity, shipments, in effect, "clone" themselves, so that one shipment traverses one of the four regional transportation routes (NE, S, SW, W), while its clone splits off to accumulate the indirect (transaction) costs of the shipment. First, the progression of shipments along the regional transportation routes will be explained, then the accumulation of indirect (transaction) shipment costs will be described.

Shipments progress along one of four transportation routes (labeled NE, S, SW, W), and then are assigned "production costs" (loading and transportation costs). The magnitude of these production costs depends on: 1) whether the shipment originated from the C or M
manufacturing site; 2) which transportation route (NE, S, SW, W) the shipment traveled; and 3) the number of miles generated from the distributions representing the distances traveled along each regional transportation route (distributions used in the transportation model are discussed below under **MODEL OPERATIONALIZATION**).

The cloned shipments advance to nodes SpTXN1, SpTXN2, and SpTXN3 where they accumulate indirect (transaction) costs. The transaction activities generating these costs include: leased fleet management activities, customer service reporting, and the tracing of delayed shipments. All three of these costs are assigned on a per shipment basis. In addition, the cost for tracing delayed shipments is modified by the number of shipments that occupy the four regional transportation routes at the time the cost of tracing shipments is computed (if there are delays that increase the number of "outstanding" shipments, the cost of tracing shipments is increased).

Both the original shipments and the cloned shipments proceed to the node labeled Sp TOTAL COST. This node collects statistics on the total cost (production + transaction) for each shipment that has traversed the Sp network. These statistics are used to provide a mean total shipment cost per year (250 days) for each replication of the model.

The Sc network employs the same procedure as the Sp network. Progression through the LOAD activity is followed by the "cloning" of shipments, and subsequent advancement through: 1) one of the four transportation routes (NE, S, SW, W) and the accumulation of production costs (for the "original" shipments), or 2) the accumulation of transaction costs in nodes ScTXN1 and ScTXN2 (for the "cloned" shipments). Finally, both the original and the cloned shipments progress to the Sc TOTAL COST node for the collection and computation of the mean shipment cost over a year. The only difference between the Sc and the Sp networks is, in the Sc network, no provision is made for
computing the cost of tracing delayed shipments. This activity does not take place when shipments are transported by a contract TL carrier.

**MODEL OPERATIONALIZATION**

This section discusses operationalization of the model's parameters and independent variables. Except for the exponential (EXPON) distribution that represented originating shipments, the distributions which were chosen to represent the model’s stochastic elements are either uniform (UNFRM) or triangular (TRIAG) distributions. The rationale behind the use of each of these three distributions is discussed below.

Exponential (EXPON) distributions are frequently used to represent outcomes or arrivals (e.g., originating shipments) which occur independently over intervals of time (Pritsker 1986). Therefore, an exponential distribution was used to represent the "arrival" of shipments to be transported. A uniform (UNFRM) distribution implies a lack of knowledge of a random variable, except for its maximum and minimum. A triangular (TRIAG) distribution implies that knowledge of a modal value, as well as a maximum and minimum value is known for a random variable. Much of the information about the elements of the transportation system that was constructed for this study was presented in discussions with Company H or Company P personnel as a maximum and a minimum (e.g., loading durations, transportation durations). Since the only parameters that were available for these distributions were maximums and minimums, this information is represented by uniform (UNFMR) distributions in the model. Other information on the elements of the transportation system was presented with some indication of a modal value, as well as a maximum and minimum (e.g., proportion of empty backhaul shipments, contract freight rates). Since the parameters available for these distributions included maximum, minimum, and mode, the information was represented by triangular (TRIAG) distributions in the model.
All of the durations for model activities (e.g., shipment loading, line haul transportation) are in days. The duration of each run, or replication of the model was one year (250 days).

The first model parameter, the time between shipments (TBS), indicates the volume of shipments (how many shipments are transported each year). As Table 8 indicates, for the VI condition (low volume), the model generates 350 shipments per year (TBS is approximately 0.71 days). This is, in fact, the volume of shipments that both manufacturing sites (C and M) generate presently for company H. This volume does not qualify company H for volume discounts on TL shipping rates from contract carriers (volume discounts would result in TL rates approximately 10% lower than the rates company H pays now for their contract shipments). To receive volume discounts on per mile TL rates, the number of shipments contracted for with a carrier must consistently exceed approximately 250 (Peterson 1994b). For the VI (low volume) condition, although company H’s two manufacturing sites, in total, generate 350 shipments per year, one site (M) generates approximately 250 shipments per year, while the other site (C), generates only 100 shipments per year. In order for both sites to consistently generate more than 250 shipments per year (which would qualify shipments from both sites for volume discounts), the total volume of shipments would have to be approximately 1200 (with a mean TBS of 0.2038 days). Therefore, for the Vh condition (high volume), the model generated approximately 1200 shipments per year.

The proportion of shipments originating from company H’s two manufacturing sites (C and M) was represented by a uniform (UNFRM) distribution, which was formulated based on information from company records.

When operating a private/leased fleet, another indication (besides shipment frequency) of resource utilization is the proportion of shipments which must return empty
### Table 8: Model Parameters and Independent Variable Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values/Operationalizations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time between shipments</td>
<td>VI: EXPON(0.71, 350) shipments/year</td>
</tr>
<tr>
<td></td>
<td>Vh: EXPON(0.2083, 1200) shipments/year</td>
</tr>
<tr>
<td>Proportion of shipments originating from C or M</td>
<td>C: UNFRM(0.2327, 0.5557)</td>
</tr>
<tr>
<td>manufacturing facility</td>
<td>M: 1 - UNFRM(0.2327, 0.5557)</td>
</tr>
<tr>
<td>Proportion of empty/full backhaul shipments</td>
<td>VI: Empty TRIA(0.35, 0.40, 0.45)</td>
</tr>
<tr>
<td></td>
<td>Full: 1 - TRIA(0.35, 0.40, 0.45)</td>
</tr>
<tr>
<td></td>
<td>Vh: Empty TRIA(0.055, 0.060, 0.065)</td>
</tr>
<tr>
<td></td>
<td>Full: 1 - TRIA(0.055, 0.060, 0.065)</td>
</tr>
<tr>
<td>Loading duration (days)</td>
<td>C: UNFRM(0.5, 1.0)</td>
</tr>
<tr>
<td></td>
<td>Un: UNFRM(0.5, 1.25)</td>
</tr>
<tr>
<td></td>
<td>M: UNFRM(0.25, 0.5)</td>
</tr>
<tr>
<td></td>
<td>Un: UNFRM(0.25, 0.75)</td>
</tr>
<tr>
<td>Cost of labor for loading</td>
<td>RNCRM(88, 4)</td>
</tr>
<tr>
<td>Transportation duration (days)</td>
<td>C: UNFRM(1.0, 1.8)</td>
</tr>
<tr>
<td></td>
<td>S: UNFRM(0.25, 1.0)</td>
</tr>
<tr>
<td></td>
<td>W: UNFRM(0.6, 1.2)</td>
</tr>
<tr>
<td></td>
<td>M: UNFRM(1.2, 2.5)</td>
</tr>
<tr>
<td></td>
<td>S: UNFRM(0.25, 1.5)</td>
</tr>
<tr>
<td></td>
<td>W: UNFRM(4.5)</td>
</tr>
<tr>
<td>Transportation distance (miles)</td>
<td>C: TRIA(400, 513, 824)</td>
</tr>
<tr>
<td></td>
<td>TRIA(350, 400, 600)</td>
</tr>
<tr>
<td></td>
<td>TRIA(105, 105, 1116)</td>
</tr>
<tr>
<td></td>
<td>TRIA(225, 200, 2070)</td>
</tr>
<tr>
<td></td>
<td>M: TRIA(51, 10, 124)</td>
</tr>
<tr>
<td></td>
<td>TRIA(35, 40, 450)</td>
</tr>
<tr>
<td></td>
<td>TRIA(0.5, 0.8, 0.9)</td>
</tr>
<tr>
<td></td>
<td>TRIA(0.7, 0.2, 0.2)</td>
</tr>
<tr>
<td>Per mile rate for private/leased shipments</td>
<td>Al full backhaul (Vh) $0.75; empty backhaul (Vh) $1.50</td>
</tr>
<tr>
<td></td>
<td>Ah full backhaul (Vh) $0.90; empty backhaul (Vh) $1.80</td>
</tr>
<tr>
<td>&quot;Fixed&quot; per shipment lease expenses</td>
<td>Al full backhaul (Vh) $478.90; empty backhaul (Vh) $957.90</td>
</tr>
<tr>
<td></td>
<td>Ah full backhaul (Vh) $574.56; empty backhaul (Vh) $1148.12</td>
</tr>
<tr>
<td>Per shipment cost for tracing private/leased</td>
<td>VI: UNFRM(23.6, 45.60)*NAC(1.41)</td>
</tr>
<tr>
<td>shipments</td>
<td>Vh: UNFRM(22.40, 45.60)*NAC(1.41)</td>
</tr>
<tr>
<td>Per shipment cost for fleet management</td>
<td>UNFRM(14.8, 102.6)</td>
</tr>
</tbody>
</table>

1 Number of Shipments in NE, S, SW, and W transportation routes
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUES/OPERATIONALIZATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per shipment cost for customer service</td>
<td>$c \text{ UNFRM(34.20,45.60)}</td>
</tr>
<tr>
<td>reporting</td>
<td>$c \text{ UNFRM(68.40,91.20)}</td>
</tr>
<tr>
<td>Per shipment cost for contract</td>
<td>$c \text{(CONTRACT) UNFRM(78.80,102.60)}</td>
</tr>
<tr>
<td>negotiation, contract carrier</td>
<td>$c \text{(THIRD PARTY) UNFRM(22.88,45.60)}</td>
</tr>
<tr>
<td>selection activities</td>
<td>$c \text{(CONTRACT) UNFRM(22.80,45.6)}</td>
</tr>
<tr>
<td>Per shipment cost for freight auditing, billing</td>
<td>$c \text{(THIRD PARTY) UNFRM(68.40,91.20)}</td>
</tr>
<tr>
<td>activities</td>
<td></td>
</tr>
<tr>
<td>Per mile TL rates</td>
<td>$^{v, ai}c$ $\text{NE TRIAG(1.20,1.65,2.00)}$</td>
</tr>
<tr>
<td>(VII)</td>
<td>$\text{S TRIAG(1.05,1.50,1.75)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{SW TRIAG(1.00,1.34,1.70)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{W TRIAG(1.00,1.10,1.55)}$</td>
</tr>
<tr>
<td>$^m$</td>
<td>$\text{NE TRIAG(1.20,1.67,2.1)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{S TRIAG(1.05,1.50,1.85)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{SW TRIAG(1.00,1.52,1.75)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{W TRIAG(1.00,1.03,1.50)}$</td>
</tr>
<tr>
<td>$^{vi, ah}$</td>
<td>$\text{NE UNFRM(1.42,1.50)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{SW UNFRM(1.41,1.50)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{W UNFRM(1.22,1.33)}$</td>
</tr>
<tr>
<td>Per mile TL rates</td>
<td>$^v h i c$ $\text{NE TRIAG(1.08,1.48,1.80)}$</td>
</tr>
<tr>
<td>(VIII)</td>
<td>$\text{S TRIAG(0.95,1.35,1.68)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{SW TRIAG(0.90,1.21,1.53)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{W TRIAG(0.80,1.07,1.40)}$</td>
</tr>
<tr>
<td>$^m$</td>
<td>$\text{NE TRIAG(1.08,1.50,1.80)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{S TRIAG(0.95,1.47,1.76)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{SW TRIAG(0.90,1.17,1.59)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{W TRIAG(0.89,0.93,1.35)}$</td>
</tr>
<tr>
<td>$^{vh, ah}$</td>
<td>$\text{NE UNFRM(1.50,1.60)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{SW UNFRM(1.30,1.45)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{SW UNFRM(1.26,1.36)}$</td>
</tr>
<tr>
<td></td>
<td>$\text{W UNFRM(1.10,1.20)}$</td>
</tr>
</tbody>
</table>

* A discussion of the results of the mean shipment cost for "Third Party" shipments appears in CHAPTER V.
(empty backhauls). Interviews with the distribution manager indicated that company H's proportion of shipments with empty backhauls was 40%. Information from company P, which is a much larger company with a correspondingly higher shipment volume, indicated that the proportion of empty backhaul shipments was 6%. Based on this information, for the private/leased network (Sp), the proportion of empty backhauls for the VI and VH conditions were 40% and 6%, respectively. It seems logical to assume that the larger and more elaborate a company's transportation network, the more opportunities it has: 1) to arrange full backhauls by transporting its own inbound materials; and/or 2) to arrange full backhauls by transporting material for other firms, if it chooses to apply for this carrier authority.

The information on the loading duration (in days) and the cost of labor for loading shipments was obtained from company H records. The transportation durations for the regional transportation routes were computed from information on the distance to each region, and were based on the following assumptions: 1) the shipment was transported "over the road" (by motor carrier only, not intermodally); 2) the carrier was driven by a single driver (not a team of two drivers, so one could sleep while the other drove); and 3) the carrier maintained an average speed of 45 mph for a period of 10 hours of driving each day.

The values for per mile and "fixed" lease expenses included the cost of a full service equipment lease, plus taxes, license fees, insurance, fuel, and maintenance costs. "Fixed" leasing expenses included: 1) a monthly cost for the full service lease on a tractor and trailer, and 2) taxes, license fees, and insurance. Per mile lease expenses included fuel and maintenance expenses (Benson 1994). For the AI (nonspecific assets) condition, fixed lease expenses for company H were obtained from company data, and a per shipment fixed expense value was computed, based on company H's average shipment distance of 1140
miles ($0.42/mile * 1140 miles/shipment = $478.80). The variable, or per mile lease expenses, which covered fuel, maintenance, and driver salaries ($0.75) were obtained from company records.

For the Ah condition (refrigerated trailers), both the fixed and variable portions of the AI lease expenses were increased by 20% ($478.80 + 20% = $574.56; $0.75 + 20% = $0.90). This increase was based on information which indicated that lease expenses (both variable and fixed portions) for refrigerated equipment were approximately 20% higher than for standard freight trailers (Benson 1994).

Obtaining values for indirect (transaction) costs (e.g., tracing delayed shipments, fleet management operations, customer service reports, carrier selection and contract negotiations, and freight auditing and billing activities, see Table 8) was difficult. The model assumed that costs for transacting activities were embedded in the clerical/management salary portion of expense statements. The rationale behind this assumption was that these activities required clerical and/or management resources, and the assumption was supported by information about "transacting" activities gained from the interviews with both company H and company P. Based on information obtained during interviews with both companies, examples of transaction activities for private/leased and contract shipments included:

1) Private/leased Shipments: tracing delayed shipments (shipments are not traced unless a customer notifies the company that the shipment is delayed); day to day fleet operations (e.g., renewing yearly equipment leases, dispatching drivers, managing payrolls, managing Department of Transportation (DOT) and Interstate Commerce Commission (ICC) requirements); and monitoring customer service outcomes.

2) Contract Shipments: gathering information on carrier firms (e.g., carriers’ service records, financial status, how competitive their rates are); negotiating carrier contracts; monitoring customer service outcomes; and auditing freight invoices (billing activities).
It is difficult, if not impossible, when gathering information from an organization whose primary business is not transportation, to separate the clerical/management resources expended on transportation activities from the resources spent on non-transportation activities within the organization. Therefore, in order to model the cost of these activities, two sources were used: 1) statistics on what proportion of transportation operating expenses represent clerical/management salaries (American Trucking Associations 1992a; Coyle, Bardi, and Cavinato 1990), and 2) information from interviews with company H and company P about the types of activities that constituted transaction activities and the relative amount of time spent on these activities for private/leased versus contract shipments.

Both Coyle, Bardi, and Cavinato and American Trucking Associations indicated that, on average, clerical/management salaries accounted for approximately 8% of total expenses for transportation operations. This percentage (8%), was used to establish per mile costs for indirect (transaction) activities; per mile costs were then converted to per shipment costs (based on company H’s average shipment distance of 1140 miles). These per shipment transaction costs were used for a series of pilot runs, in order to establish values for transaction costs that represented approximately 8% of the total shipment costs over all private/leased (Sp) conditions².

There were five categories of transaction activities identified from information gathered in interviews with company H (these categories were supported by information obtained from company P). The categories and their parameters, which appear in Table 8, included: tracing delayed shipments (private/leased shipments only); fleet management

²Once the per shipment costs for transaction activities in the private/leased (Sp) network were established by the pilot runs, these costs were modified based on information obtained from interviews with company H and company P about the relative amount of time spent on transacting activities for private/leased versus contract shipments.
operations (private/leased shipments only); customer service reporting (both private/leased and contract shipments); carrier selection and contract negotiations (contract shipments only); auditing and payment of freight bills (contract shipments only). Except for the category "tracing delayed shipments," the model accumulated costs for these activities solely on a per shipment basis.

The cost of tracing delayed shipments reflected the low and high uncertainty (Ul and Uh) conditions. Based on information from company H on durations for loading and transportation of shipments, low (Ul) and high (Uh) uncertainty were represented by two sets of uniform (UNFRM) distributions for loading and transportation durations (in days). The distributions for low uncertainty (Ul) reflected loading and transportation durations to each region when no operational delays occurred (e.g., no bad weather, no delays due to road construction), and represented predictable durations for these activities. The distributions for high uncertainty (Uh) reflected the loading and transportation durations to each region when there were operational delays.

According to the distribution manager of company H, if shipments arrive at their destinations within the expected length of time, time spent tracing shipments is nominal. However, circumstances which cause shipments to be delayed enroute (e.g., bad weather), thereby making less predictable their arrival to the respective destinations, tend to increase the time devoted to tracing shipments. To model the cost of tracing shipments, the model initially assigned a cost per shipment. Subsequently, this "basic" cost per shipment was modified according to whether or not there were shipments being detained along the four regional transportation routes. Pilot runs of the model established a mean number of "outstanding" shipments for the low uncertainty condition (Ul) for both low and high volume (Vl and Vh) (see Table 8, values for Vl and Vh (4.354 and 12.24), "Per shipment cost for tracing private/leased shipments). This mean number of outstanding shipments was used to
form a ratio (the actual number of outstanding shipments at a given time/the mean number of outstanding shipments), which modified the per shipment cost of tracing delayed shipments.

Information on per mile TL freight rates for the low volume (VI), low asset specificity (AI) conditions was obtained from interviews with the distribution manager of company H, since this company’s volume of shipments in standard trailers was reflected in the AI and VI conditions of the model. Information on per mile contract TL rates for the high volume (Vh), high asset specificity (Ah) conditions was obtained from company records of company P, since their high volume of shipments in refrigerated trailers reflected the Ah and Vh conditions. The TL rates for low volume (VI), high asset specificity (Ah) conditions were obtained by increasing the rates for high volume (Vh), high asset specificity (Ah) by 10%. Volume discounts generally reduce TL contract rates by approximately 10% (Peterson 1994a; Stewart 1994b). Therefore, increasing the rates by 10% for company P’s high volume (hence discounted) refrigerated shipments represented the low volume (VI), high asset specificity (Ah) conditions. TL rates for the high volume (Vh), low asset specificity condition (AI) were represented by discounting company H’s low volume (undiscounted) rates by 10%.

The principal factor guiding TL contract rates (besides a shipper’s volume) appeared to be the availability of freight for the carrier to “backhaul” from a shipment’s destination. Some regions of the country have relatively little freight departing from them. For these regions of the country (e.g., NE), the per mile rate can be quite high when compared to regions of the country that have a relative abundance of freight originating from them (e.g., W). Examination of the distributions (in Table 8) that represented the TL rates for each of the transportation regions (NE, S, SW, W) reveals evidence of this pattern.
Table 9 details cell treatments for each of the 16 cells in the experimental design. Specific values for the levels of the independent variables which constituted each cell treatment can be found in Table 8.

This section has described the transportation model, explained how the model was operationalized, and detailed cell treatments for the experimental design. The next section discusses investigation of the model prior to conducting the proposed experiments. This investigation consisted of: 1) determining the model’s steady-state behavior; 2) model verification and validation; and 3) ascertaining the sample size required for the desired relative precision of the model’s output (total shipment cost).

INVESTIGATION OF MODEL OPERATION

STEADY-STATE BEHAVIOR

In order to determine whether initial model conditions caused a bias in the model’s output values, the mean and standard deviation of the model’s output (mean total shipment cost) was graphed during a series of pilot runs. Output from both the Sp and Sc networks was graphed (see graphs for Private/Leased Network (Sp) and Contract Network (Sc) in Figure 6). Each of these graphs was generated by discarding (clearing the model’s statistical counters) output statistics on mean total shipment cost at successive points (refer to STATISTICAL ARRAYS CLEARED on the horizontal axes of the two graphs in Figure 6). For example, the first pilot run discarded none of the model’s total shipment cost output statistics (STATISTICAL ARRAYS CLEARED = 0); the second run discarded the first 5 days of output statistics (STATISTICAL ARRAYS CLEARED = 5); the third run discarded the first 10 days of output statistics, and so on, up to discarding the first 100 days of output statistics (STATISTICAL ARRAYS CLEARED = 100). Increasing or decreasing trends in the mean of total shipment cost and/or instability in the variability (standard deviation) of total
## TABLE 9  DETAILS OF CELL TREATMENTS

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>S</th>
<th>A</th>
<th>U</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1111</td>
<td>private/leased carrier</td>
<td>standard trailer</td>
<td>predictable loading, transportation duration</td>
<td>350 shipments/year</td>
</tr>
<tr>
<td>1112</td>
<td>private/leased carrier</td>
<td>standard trailer</td>
<td>predictable loading, transportation duration</td>
<td>1200 shipments/year</td>
</tr>
<tr>
<td>1121</td>
<td>private/leased carrier</td>
<td>standard trailer</td>
<td>unpredictable loading, transportation duration</td>
<td>350 shipments/year</td>
</tr>
<tr>
<td>1122</td>
<td>private/leased carrier</td>
<td>standard trailer</td>
<td>unpredictable loading, transportation duration</td>
<td>1200 shipments/year</td>
</tr>
<tr>
<td>1211</td>
<td>private/leased carrier</td>
<td>refrigerated trailer</td>
<td>predictable loading, transportation duration</td>
<td>350 shipments/year</td>
</tr>
<tr>
<td>1212</td>
<td>private/leased carrier</td>
<td>refrigerated trailer</td>
<td>predictable loading, transportation duration</td>
<td>1200 shipments/year</td>
</tr>
<tr>
<td>1221</td>
<td>private/leased carrier</td>
<td>refrigerated trailer</td>
<td>unpredictable loading, transportation duration</td>
<td>350 shipments/year</td>
</tr>
<tr>
<td>1222</td>
<td>private/leased carrier</td>
<td>refrigerated trailer</td>
<td>unpredictable loading, transportation duration</td>
<td>1200 shipments/year</td>
</tr>
<tr>
<td>2111</td>
<td>contract carrier</td>
<td>standard trailer</td>
<td>predictable loading, transportation duration</td>
<td>350 shipments/year</td>
</tr>
<tr>
<td>2112</td>
<td>contract carrier</td>
<td>standard trailer</td>
<td>predictable loading, transportation duration</td>
<td>1200 shipments/year</td>
</tr>
<tr>
<td>2121</td>
<td>contract carrier</td>
<td>standard trailer</td>
<td>unpredictable loading, transportation duration</td>
<td>350 shipments/year</td>
</tr>
<tr>
<td>2122</td>
<td>contract carrier</td>
<td>standard trailer</td>
<td>unpredictable loading, transportation duration</td>
<td>1200 shipments/year</td>
</tr>
<tr>
<td>2211</td>
<td>contract carrier</td>
<td>refrigerated trailer</td>
<td>predictable loading, transportation duration</td>
<td>350 shipments/year</td>
</tr>
<tr>
<td>2212</td>
<td>contract carrier</td>
<td>refrigerated trailer</td>
<td>predictable loading, transportation duration</td>
<td>1200 shipments/year</td>
</tr>
<tr>
<td>2221</td>
<td>contract carrier</td>
<td>refrigerated trailer</td>
<td>unpredictable loading, transportation duration</td>
<td>350 shipments/year</td>
</tr>
<tr>
<td>2222</td>
<td>contract carrier</td>
<td>refrigerated trailer</td>
<td>unpredictable loading, transportation duration</td>
<td>1200 shipments/year</td>
</tr>
</tbody>
</table>
shipment cost indicates that initial model conditions are biasing the model’s output statistics.

Neither of the graphs in Figure 6 exhibit increasing/decreasing trends in mean total shipment cost, or evidence of instability in the variability (standard deviation) of total shipment cost. Therefore, the model’s initial conditions are not biasing the output statistics and truncation procedures were not required.

MODEL VERIFICATION AND VALIDATION

Model verification procedures endeavor to make sure the simulation model is executing as the modeler directed. Techniques for model validation seek some degree of confirmation that the simulation model is an accurate representation of the system of interest (Law and Kelton 1982).

Verification

Model verification consisted of two techniques. First, as the model was being constructed, model elements were tested through the use of deterministic (rather than probabilistic) durations, distances, and costs. Table 10 contains the results of testing the following model elements: TBS (time between shipments, indicating shipment volume); the proportion of shipments dispatched to the four regional transportation routes (NE, S, SW, S); the proportion of shipments originating from the C and M manufacturing sites; and the proportion of shipments characterized by empty/full backhauls. There are two columns of figures in Table 10. The first column of figures contains the value that would be expected if the element of the model that is being tested is performing correctly (VERIFICATION VALUE); the second column of figures contains the value actually generated by the model
PRIVATE/LEASED NETWORK

![Graph showing the total shipment cost for statistical arrays cleared.]

- Mean Shipment Cost
- SD Shipment Cost

CONTRACT NETWORK

![Graph showing the total shipment cost for statistical arrays cleared.]

- Mean Shipment Cost
- SD Shipment Cost

FIGURE 6  STEADY STATE BEHAVIOR
(MODEL VALUE). Verification consisted of ensuring that the values were the same in both columns. As Table 10 demonstrates, the model appears to perform correctly with regard to these elements.

The second technique, known as a trace, provided "snapshots" of the completed model's operation. A trace was performed for both the Sp (private/leased) network and the Sc (contract) network. The following model elements were evaluated for the Sp network: loading durations and transportation durations; transportation distances for each regional transportation route; computation of variable (per mile) and fixed equipment expenses; ratio for modifying the cost for tracing delayed shipments; computation of transaction costs; computation of "production" costs (loading and line haul transportation costs); and computation of total costs (transaction + production). An excerpt from the trace report for the Sp network appears in Table 11. Table 11 contains two columns of figures. The first column of figures (APPROXIMATE VERIFICATION VALUES) contains values indicating the approximate\(^3\) value expected if the model is performing correctly. The second column of figures (MODEL VALUES) contains the values generated by the model. A comparison of the values in Table 11 indicates that the Sp network performed correctly.

Table 12 contains an excerpt from the trace report for the verification of the Sc network. Comparison of the values in the two columns of figures (APPROXIMATE VERIFICATION VALUES and MODEL VALUES) reveals that the Sc network also performed correctly.

---

\(^3\) The reason that the verification values in Tables 11 and 12 are approximate is that, for the trace report, parameters similar to the distributions in Table 8 were used in the model. Since the values generated from these distributions were random numbers, verification values given in Tables 11 and 12 are either the minimum and maximum (for a uniform distribution) or the mode (for a triangular distribution).
<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>VERIFICATION VALUE</th>
<th>MODEL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBS (time between shipments) / # shipments/year</td>
<td>TBS = 2.50 / 100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>TBS = 0.25 / 1000</td>
<td>1000</td>
</tr>
<tr>
<td>Sp Network:</td>
<td>NE = 40%</td>
<td>39.2%</td>
</tr>
<tr>
<td>Propportion of Shipments in Regional Transportation Routes (NE, S, SW, W)</td>
<td>S = 20%</td>
<td>20.5%</td>
</tr>
<tr>
<td></td>
<td>SW = 10%</td>
<td>10.1%</td>
</tr>
<tr>
<td></td>
<td>W = 30%</td>
<td>30.2%</td>
</tr>
<tr>
<td>Sc Network:</td>
<td>NE = 40%</td>
<td>41.7%</td>
</tr>
<tr>
<td>Propportion of Shipments in Regional Transportation Routes (NE, S, SW, W)</td>
<td>S = 20%</td>
<td>18.7%</td>
</tr>
<tr>
<td></td>
<td>SW = 10%</td>
<td>9.9%</td>
</tr>
<tr>
<td></td>
<td>W = 30%</td>
<td>29.7%</td>
</tr>
<tr>
<td>Propportion of Shipments Originating from C and M Plants</td>
<td>C = 30%</td>
<td>31.3%</td>
</tr>
<tr>
<td></td>
<td>M = 70%</td>
<td>68.7%</td>
</tr>
<tr>
<td>Propportion of Empty/Full Backhaul Shipments</td>
<td>Empty = 40%</td>
<td>41%</td>
</tr>
<tr>
<td></td>
<td>Full = 60%</td>
<td>59%</td>
</tr>
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### TABLE 11  EXCERPT FROM TRACE REPORT FOR Sp (Private/Leased) NETWORK

<table>
<thead>
<tr>
<th>MODEL ELEMENT</th>
<th>(APPROXIMATE) VERIFICATION VALUE</th>
<th>MODEL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading Duration</td>
<td>C = 0.50-1.00, M = 0.25-0.50</td>
<td>0.708, 0.358</td>
</tr>
<tr>
<td>Line Haul Transportation Duration - Plant C</td>
<td>NE = 1.00-1.50, S = 0.25-1.00, SW = 2.25-2.50, W = 5.00-6.00</td>
<td>1.46, 0.68, 2.42, 5.86</td>
</tr>
<tr>
<td>Line Haul Transportation Duration - Plant M</td>
<td>NE = 1.00-2.75, S = 0.50-1.00, SW = 1.25-1.50, W = 4.00-4.50</td>
<td>1.61, 0.66, 1.37, 4.47</td>
</tr>
<tr>
<td>Transportation Distance (miles) - Plant C</td>
<td>NE = 513, S = 400, SW = 1068, W = 2400</td>
<td>577, 405, 1040, 2410</td>
</tr>
<tr>
<td>Transportation Distance (miles) - Plant M</td>
<td>NE = 940, S = 400, SW = 580, W = 2020</td>
<td>597, 365, 599, 2050</td>
</tr>
<tr>
<td>Variable (per mile) / Fixed Lease Expenses for Empty and Full Backhaul Shipments</td>
<td>Empty = 0.75 / 478.80, full = 1.50 / 957.60</td>
<td>0.75 / 478.00, 1.50 / 957.60</td>
</tr>
<tr>
<td>Ratio of Current Number of Shipments in Transit (i.e., traversing the four regional transportation routes) to Mean Number of Shipments in Transit</td>
<td>0.0186, 1.1560, 0.6990</td>
<td>0.0180, 1.1500, 0.6890</td>
</tr>
<tr>
<td>Cost of Handling Delayed Shipment</td>
<td>22.82, 24.60, 18.50</td>
<td>22.82, 24.60, 18.50</td>
</tr>
<tr>
<td>Cost of Managing Fleet Operations</td>
<td>57.00-79.80</td>
<td>63.00, 73.00, 63.00</td>
</tr>
<tr>
<td>Cost of Monitoring CS</td>
<td>11.40-34.2</td>
<td>25.50, 15.40, 24.50</td>
</tr>
<tr>
<td>Total Transaction Cost</td>
<td>88.82, 106.00, 110.30</td>
<td>88.80, 106.00, 110.00</td>
</tr>
<tr>
<td>Total Shipment Cost</td>
<td>1246.00, 1473.00, 1266.00</td>
<td>1250.00, 1470.00, 1270.00</td>
</tr>
</tbody>
</table>

1 Minimum, Maximum from UNFRM Distribution
2 Mode from TRIAG Distribution
<table>
<thead>
<tr>
<th>MODAL ELEMENT</th>
<th>(APPROXIMATE) VERIFICATION VALUE</th>
<th>MODEL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL Contract Rates - Plant C</td>
<td>NE = 1.20-2.00</td>
<td>1.81</td>
</tr>
<tr>
<td></td>
<td>S = 1.05-1.75</td>
<td>1.53</td>
</tr>
<tr>
<td></td>
<td>SW = 1.00-1.70</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>W = 1.00-1.55</td>
<td>1.10</td>
</tr>
<tr>
<td>TL Contract Rates - Plant M</td>
<td>NE = 1.20-2.00</td>
<td>1.83</td>
</tr>
<tr>
<td></td>
<td>S = 1.05-1.96</td>
<td>1.85</td>
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<tr>
<td></td>
<td>SW = 1.00-1.75</td>
<td>1.24</td>
</tr>
<tr>
<td></td>
<td>W = 1.00-1.50</td>
<td>1.16</td>
</tr>
<tr>
<td>Loading Duration</td>
<td>C = 0.50-1.00</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>M = 0.26-0.50</td>
<td>0.36</td>
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<tr>
<td>Line Haul Transportation Duration - Plant C</td>
<td>NE = 1.00-1.50</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>S = 0.26-1.00</td>
<td>0.42</td>
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<tr>
<td></td>
<td>SW = 2.25-2.50</td>
<td>2.29</td>
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<tr>
<td></td>
<td>W = 5.00-6.00</td>
<td>5.01</td>
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<tr>
<td>Line Haul Transportation Duration - Plant M</td>
<td>NE = 1.00-2.75</td>
<td>1.45</td>
</tr>
<tr>
<td></td>
<td>S = 0.50-1.00</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>SW = 1.25-1.50</td>
<td>1.48</td>
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<tr>
<td></td>
<td>W = 4.00-4.50</td>
<td>4.28</td>
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<tr>
<td>Transportation Distance (miles) - Plant C</td>
<td>NE = 513</td>
<td>603</td>
</tr>
<tr>
<td></td>
<td>S = 400</td>
<td>425</td>
</tr>
<tr>
<td></td>
<td>SW = 1086</td>
<td>1070</td>
</tr>
<tr>
<td></td>
<td>W = 2400</td>
<td>2290</td>
</tr>
<tr>
<td>Transportation Distance (miles) - Plant M</td>
<td>NE = 400</td>
<td>668</td>
</tr>
<tr>
<td></td>
<td>S = 400</td>
<td>395</td>
</tr>
<tr>
<td></td>
<td>SW = 580</td>
<td>570</td>
</tr>
<tr>
<td></td>
<td>W = 2020</td>
<td>2050</td>
</tr>
<tr>
<td>Cost of Contract Negotiations, Carrier Selection</td>
<td>57.00-79.8</td>
<td>59.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>74.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>59.00</td>
</tr>
<tr>
<td>Cost of Monitoring CS</td>
<td>45.6-68.4</td>
<td>54.7</td>
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<tr>
<td></td>
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<td>61.5</td>
</tr>
<tr>
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<td></td>
<td>66.8</td>
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<td>Billing Costs</td>
<td>11.40-34.2</td>
<td>32.30</td>
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<td></td>
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<td>17.80</td>
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<td>20.90</td>
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<td>Total Transaction Cost</td>
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<td>153.80</td>
<td>154.00</td>
</tr>
<tr>
<td></td>
<td>146.70</td>
<td>146.00</td>
</tr>
<tr>
<td>Total Shipment Cost (transaction → production)</td>
<td>1767.54</td>
<td>1760.00</td>
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<tr>
<td></td>
<td>2604.00</td>
<td>2600.00</td>
</tr>
<tr>
<td></td>
<td>2364.00</td>
<td>2360.00</td>
</tr>
</tbody>
</table>

1 Minimum, Maximum from UNFRM Distribution  
2 Mode from TRIAG Distribution

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Validation

Model validation consisted of two procedures. The first procedure investigated how sensitive the model’s output statistics were to changes in the assumptions made for the distribution of transportation distances (in miles). The model assumed that a triangular (TRIAG) distribution represented the distances (in miles) for the four regional transportation routes. Testing assumptions about this distribution was relevant because, given the structure of the model, it was likely to have the most significant effect on the response variable (mean total shipment cost). Figure 7 demonstrates the effect on the response variable (mean total shipment cost) of changing the form of this distribution (transportation distance in miles) from triangular (TRIAG) to uniform (UNFRM). Because of the model’s structure, the effects of changing the form of this distribution was tested for both the private/leased and the contract portions of the model (Sp Network and Sc Network). The portion of the model (Sp or Sc) that was tested is indicated on the horizontal axis of the graph in Figure 7. As Figure 7 indicates, changing the form of this distribution had little effect on the response variable (mean total shipment cost). Significance testing for differences in the response variable (see Table 13) confirmed the model’s lack of sensitivity to changing the form of the distribution used to represent transportation distance.

The second validation procedure was a comparison of the simulated loading and line haul transportation costs with the loading and line haul transportation cost data supplied by company H. Figure 8 represents graphically the differences between the actual production cost (actual cost) and the production cost generated by the model (model cost). Since company H is currently operating under a “mixed” structure, i.e., some of their shipments go in private/leased carriers and some of their shipments go in contract carriers, production costs for both conditions could be obtained for validation of the model. As Figure 8 demonstrates, there is very little difference between the actual and model production costs.
Furthermore, Table 14 confirms that the actual and model costs are not significantly different, since the 95% confidence intervals for the model production costs contain the actual production cost values.

**DETERMINATION OF SAMPLE SIZE**

As was explained in CHAPTER III (see *Stochastic Convergence, Variance Reduction Techniques, and Sample Size*), the relative precision of the estimates of mean total shipment cost has an impact on the power of the statistical tests of the proposed hypotheses. The more precise (i.e., the smaller the within cell variance or the standard deviation within each cell) the estimates of mean total shipment cost are, the greater the probability of detecting a significant result for a proposed hypothesis. The target value for the relative precision (\(\gamma\)) of the model’s output statistics was 0.05. The relative precision is the ratio of the half-width of the confidence-interval (\(\delta\)) to the sample mean (\(\bar{X}\)). Therefore, a target value of 0.05 means that the sample size should be large enough so that (\(\delta/\bar{X}\)) does not exceed 0.05. An initial sample size of 10 (\(n_0 = 10\)) was chosen and the relative precision of 90% confidence intervals was computed for each cell in the experimental design.

Table 15 contains the sample mean (\(\bar{X}_{1(n)}\)), standard deviation (\(s_{1(n)}\)), half-width of the 90% confidence interval (\(\delta_{15,10}\)), and relative precision (\(\gamma\)) for each of the 16 experimental conditions. Since the relative precision for each cell (see last column, RELATIVE PRECISION (\(\gamma\))) is less than the target value of 0.05 (\(\gamma < 0.05\) for each cell), a
<table>
<thead>
<tr>
<th></th>
<th>Distance (TRIAG)</th>
<th>Distance (UNFRM)</th>
<th>t / sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sp</td>
<td>2010</td>
<td>1998</td>
<td>0.43 / ns*</td>
</tr>
<tr>
<td>Sc</td>
<td>1743</td>
<td>1724</td>
<td>0.82 / ns*</td>
</tr>
</tbody>
</table>

* Not-Significant
<table>
<thead>
<tr>
<th></th>
<th>Actual Production Cost</th>
<th>Model Production Cost (Mean)</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRIVATE/LEASED CARRIERS</td>
<td>1871.00</td>
<td>1854.00</td>
<td>1810.47, 1897.53</td>
</tr>
<tr>
<td>CONTRACT CARRIERS</td>
<td>1522.00</td>
<td>1544.00</td>
<td>1509.07, 1578.93</td>
</tr>
<tr>
<td>CELL</td>
<td>MEAN ( (\bar{x}_{i10}) )</td>
<td>STD DEV ( (s_{i10}) )</td>
<td>HALF-WIDTH OF 90% CONFIDENCE INTERVAL ( (\delta_{i10-10}) )</td>
</tr>
<tr>
<td>------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>2010.0</td>
<td>62.77</td>
<td>11.51</td>
</tr>
<tr>
<td>2</td>
<td>1575.0</td>
<td>16.88</td>
<td>3.09</td>
</tr>
<tr>
<td>3</td>
<td>2078.0</td>
<td>59.30</td>
<td>10.87</td>
</tr>
<tr>
<td>4</td>
<td>1605.0</td>
<td>16.28</td>
<td>2.98</td>
</tr>
<tr>
<td>5</td>
<td>2387.9</td>
<td>53.18</td>
<td>9.75</td>
</tr>
<tr>
<td>6</td>
<td>1862.0</td>
<td>19.90</td>
<td>3.65</td>
</tr>
<tr>
<td>7</td>
<td>2379.0</td>
<td>101.53</td>
<td>18.61</td>
</tr>
<tr>
<td>8</td>
<td>1887.0</td>
<td>21.93</td>
<td>4.02</td>
</tr>
<tr>
<td>9</td>
<td>1743.0</td>
<td>51.97</td>
<td>9.53</td>
</tr>
<tr>
<td>10</td>
<td>1572.0</td>
<td>17.21</td>
<td>3.15</td>
</tr>
<tr>
<td>11</td>
<td>1712.0</td>
<td>47.71</td>
<td>8.75</td>
</tr>
<tr>
<td>12</td>
<td>1593.0</td>
<td>31.00</td>
<td>5.68</td>
</tr>
<tr>
<td>13</td>
<td>1808.0</td>
<td>74.00</td>
<td>13.56</td>
</tr>
<tr>
<td>14</td>
<td>1646.0</td>
<td>27.28</td>
<td>5.00</td>
</tr>
<tr>
<td>15</td>
<td>1784.0</td>
<td>59.20</td>
<td>10.85</td>
</tr>
<tr>
<td>16</td>
<td>1663.0</td>
<td>27.59</td>
<td>5.06</td>
</tr>
</tbody>
</table>
sample size of 10 was sufficient for the desired relative precision.\footnote{The relative precision results in Table 15 appear to indicate that a sample size of 10 was more than sufficient for the desired degree of relative precision. However, Law and Kelton’s (1982) recommendation for an initial sample size was $n_0 \geq 10$ (see \textit{Stochastic Convergence, Variance Reduction Techniques, and Sample Size} in \textit{CHAPTER III}). Therefore 10 ($n_0 = 10$) was the initial sample size used in this procedure.}

**EXPERIMENTAL RESULTS**

This section discusses the analysis of the $2^4$ factorial design. The first part of this discussion includes the results of the analysis of variance, and the second part of the discussion presents the results of the comparisons of groups and pairs of cell means that test the a priori contrasts stated in hypotheses 1 - 7.

**RESULTS: ANALYSIS OF VARIANCE**

Table 17 contains the cell means (mean total shipping costs) for each of the sixteen cells of the experimental design. The data in Table 17 was used to test the contrasts among groups and pairs of cell means that were predicted by the seven sets of hypotheses. Table 17 also contains the percentage of mean total shipping costs accounted for by transaction costs (these percentages are discussed in \textit{CHAPTER V} under \textbf{HYPOTHESIS 2}).

In Figures 9 through 15 the results of the analysis for each of the seven sets of hypotheses are presented graphically. The solid lines in Figures 9 through 15 represent cell means or groups of cell means with significant differences between the mean shipment cost for private/leased carriers (Sp) versus contract carriers (Sc). The broken lines in Figures 9 through 15 represent cell means or groups of cell means with nonsignificant differences
between the mean shipment cost for private/leased carriers (Sp) versus contract carriers (Sc). Superimposed in the top right corner of each graph in Figures 9 through 15 is a smaller graph showing the pattern that was predicted by the hypothesis.

Table 16 contains the main effects and interaction results of the results of the analysis of variance. These results indicate that the hypothesized third order interaction of structure (S) by asset specificity (A) by uncertainty (U) by volume (V) was not significant. One of the hypothesized second order interactions (structure (S) by asset specificity (A) by volume (V)) was marginally significant (0.079), indicating that volume modified effect of the structure (S) by asset specificity (A) interaction. The second order interaction of structure (S) by uncertainty (U) by volume (V) was nonsignificant, as hypothesized. The hypothesized second order interaction of structure (S) by asset specificity (A) by uncertainty (U) was not significant, indicating that uncertainty does not modify the first order interaction of structure and asset specificity. Two of the hypothesized first order interactions (structure (S) by asset specificity (A) and structure (S) by volume (V)) were significant, indicating that the effects of structure on shipment cost depend on the level of asset specificity (low or high) and the level of volume (low or high). The other first order interaction (structure (S) by uncertainty (U)) was marginally significant (0.049), indicating that the effect of structure on shipment cost depends on the level of uncertainty (low or high); this result was not hypothesized.

RESULTS: COMPARISONS OF GROUPS AND PAIRS OF CELL MEANS

This section contains the results of the comparisons among groups and pairs of cell means that were predicted by hypotheses 1 - 7. Two different procedures were used to test the research hypotheses. When a hypothesis required testing a contrast among groups
### TABLE 16
ANALYSIS OF VARIANCE
DEPENDENT VARIABLE MEAN TOTAL SHIPMENT COST

<table>
<thead>
<tr>
<th>SOURCE OF VARIATION</th>
<th>SUM OF SQUARES</th>
<th>DF</th>
<th>MEAN SQUARE</th>
<th>F</th>
<th>SIG OF F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within + Residual</td>
<td>405152.92</td>
<td>148</td>
<td>2737.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>3200447.76</td>
<td>1</td>
<td>3200447.80</td>
<td>1169.10</td>
<td>0.000</td>
</tr>
<tr>
<td>A</td>
<td>1460959.51</td>
<td>1</td>
<td>1460959.50</td>
<td>533.68</td>
<td>0.000</td>
</tr>
<tr>
<td>U</td>
<td>5892.76</td>
<td>1</td>
<td>5892.76</td>
<td>2.15</td>
<td>0.144</td>
</tr>
<tr>
<td>V</td>
<td>3902813.26</td>
<td>1</td>
<td>3902813.26</td>
<td>1425.67</td>
<td>0.000</td>
</tr>
<tr>
<td>S BY A</td>
<td>548309.76</td>
<td>1</td>
<td>548309.76</td>
<td>213.44</td>
<td>0.000</td>
</tr>
<tr>
<td>S BY U</td>
<td>10742.01</td>
<td>1</td>
<td>10742.01</td>
<td>3.92</td>
<td>0.049</td>
</tr>
<tr>
<td>S BY V</td>
<td>1143961.51</td>
<td>1</td>
<td>1143961.51</td>
<td>417.88</td>
<td>0.000</td>
</tr>
<tr>
<td>S BY A BY U</td>
<td>4505.01</td>
<td>1</td>
<td>4505.01</td>
<td>1.65</td>
<td>0.202</td>
</tr>
<tr>
<td>S BY A BY V</td>
<td>8541.01</td>
<td>1</td>
<td>8541.01</td>
<td>3.12</td>
<td>0.079</td>
</tr>
<tr>
<td>S BY U BY V</td>
<td>5892.76</td>
<td>1</td>
<td>5892.76</td>
<td>2.15</td>
<td>0.144</td>
</tr>
<tr>
<td>S BY A BY U BY V</td>
<td>4295.26</td>
<td>1</td>
<td>4295.26</td>
<td>1.57</td>
<td>0.212</td>
</tr>
<tr>
<td>Model</td>
<td>10332380.57</td>
<td>11</td>
<td>939305.51</td>
<td>343.12</td>
<td>0.000</td>
</tr>
<tr>
<td>Total</td>
<td>10732513.49</td>
<td>159</td>
<td>6753.15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R-Squared = 0.962
Adjusted R-Squared = 0.953
<table>
<thead>
<tr>
<th>Private/Leased CARRIER</th>
<th>Predictable Loading, Transportation Duration</th>
<th>Low Vol</th>
<th>High Vol</th>
<th>Predictable Loading, Transportation Duration</th>
<th>Low Vol</th>
<th>High Vol</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2010 (8.5%)</td>
<td>$1575 (9.9%)</td>
<td></td>
<td></td>
<td>$2389 (7.1%)</td>
<td></td>
<td>$1862 (9.2%)</td>
</tr>
<tr>
<td>$2078 (9.0%)</td>
<td>$1605 (11.8%)</td>
<td></td>
<td></td>
<td>$2379 (8.4%)</td>
<td></td>
<td>$1887 (10%)</td>
</tr>
<tr>
<td>Contract Carrier</td>
<td>Predictable Loading, Transportation Duration</td>
<td>$1743 (11.8%)</td>
<td>$1572 (13.1%)</td>
<td>$1808 (11.4%)</td>
<td>$1646 (12.4%)</td>
<td></td>
</tr>
<tr>
<td>$1712 (12%)</td>
<td>$1593 (12.9%)</td>
<td></td>
<td></td>
<td>$1784 (11.5%)</td>
<td></td>
<td>$1663 (12.3%)</td>
</tr>
</tbody>
</table>

1: The quantity in each cell is the mean total shipping cost; quantity in parentheses is the percentage of mean total shipping cost accounted for by transaction costs.
FIGURE 9  H1A, H1B AND H2
FIGURE 11  H4A, H4B
FIGURE 12  H5A, H5B
FIGURE 13  H6A, H6B
FIGURE 14  H7A
of cell means, Scheffe’s S method was used. When a hypothesis required testing a contrast among a pair of cell means, the more powerful Fisher Least Significant Difference (LSD) method was used. Scheffe’s method is less suitable for comparisons of cell means than Fisher’s LSD, because of its lack of power to detect differences between pairs of cell means (Ott 1988).

**Scheffe’s S Test**

The following procedure, from Ott (1988), was used for the comparison of groups of cell means.

1. \( I \) is a linear contrast among \( t \) means of the form:
   \[ I = a_1 \mu_1 + a_2 \mu_2 + \ldots + a_t \mu_t \]

2. To test the null hypothesis, \( H_0: I = 0 \), against the alternative, \( H_1: I \neq 0 \), use the following test statistic:
   \[ \bar{I} = a_1 \bar{Y}_1 + a_2 \bar{Y}_2 + \ldots + a_t \bar{Y}_t \]

3. \( S = \sqrt{\frac{v(l)(t-1)}{\sum (a_i^2/n_i + a_i^2/n_i + \ldots)}} \frac{F_{a_i,df_1,df_2}}{F_{a_i,df_1,df_2}} \) where \( v(l) = s^2_w \), \( df_1 = t - 1 \), \( df_2 \) = degrees of freedom for \( s^2_w \).

4. Reject \( H_0 \) if \( |\bar{I}| > S \).

5. The error rate is controlled on an experimentwise basis; the probability of falsely observing significance when all possible contrasts are considered is \( \alpha \).

**Fisher’s LSD Test**

For comparisons of pairs of cell means, the following procedure, suggested by Ott (1988) was followed.

1. If an analysis of variance suggests that at least one pair of cell means differs, the least significant difference (LSD) is the difference between two cell means that is required to conclude that the corresponding population means differ.

2. To test the null hypothesis, \( H_0: \mu_1 - \mu_2 = 0 \), against the alternative, \( H_1: \mu_1 - \mu_2 \neq 0 \), for a specified \( \alpha \) (if \( n_1 = n_2 \)), compute LSD:
   \[ LSD = t_{\alpha/2} \sqrt{2s^2_w/n} \]
3. The error rate (probability of observing a contrast falsely significant) is $\alpha$ for each pairwise contrast.

**HYPOTHESES TEST RESULTS**

This section reports the results of the analyses which determined which of the seven sets of research hypotheses was supported. A discussion of these results appears in CHAPTER V. The following protocol was used for the hypotheses tests:

1. Hypotheses requiring the testing of the mean of groups of cells were performed using Scheffe’s S procedure. Hypotheses requiring the testing of a pair of cell means were performed using Fisher’s LSD.

2. For all comparisons, $\alpha = 0.05$.

**H1A and H1B**

H1A Over all conditions of uncertainty and volume, the more efficient alternative (measured by mean shipment cost) for shipments requiring standard trailers (Al) will be contract carriers (Sc) (Al has a negative slope).

H1B Over all conditions of uncertainty and volume, the more efficient alternative (measured by mean shipment cost) for shipments requiring refrigerated trailers (Ah) will be private/leased carriers (Sp) (Ah has a positive slope)

A - Mean for cells in private/leased carriers (Sp) and low asset specificity (Al) 1817.00

B - Mean for cells in contract carriers (Sc) and low asset specificity (Al) 1655.00

C - Mean for cells in private/leased carriers (Sp) and high asset specificity (Ah) 2128.98

D - Mean for cells in contract carriers (Sc) and high asset specificity (Ah) 1725.75

$A - B$ not significant

$C - D$ significant
The analysis of variance supported the prediction of a significant interaction between structure (S) and asset specificity (A); the effect of structure on cost depended on the level of asset specificity (see Figure 9). However, while contract carriers were more efficient when shipments required standard trailers, as predicted by H1A (A - B), this difference in cost was not significant (see Figure 9).

H1B predicted shipments requiring refrigerated trailers would be more efficient if shipped in private/leased carriers (C - D). This hypothesis was not supported. The opposite result was obtained, i.e., contract carriers were significantly more efficient than private/leased carriers (see Figure 9).

H2

H2: Over all conditions of asset specificity and volume, there will be no significant difference between the mean cost of shipments in private/leased carriers (Sp) and the mean cost of shipments in contract carriers (Sc); this will be true no matter what the level of operational uncertainty is (low (Ul) or high (Uh)) (both Ul and Uh have a slope of 0)

A - Mean of cells in private/leased carriers (Sp) and low uncertainty (Ul) 1958.73

B - Mean of cells in contract carriers (Sc) and low uncertainty (Ul) 1692.25

C - Mean of cells in private/leased carriers (Sp) and high uncertainty (Uh) 1987.25

D - Mean of cells in contract carriers (Sc) and high uncertainty (Uh) 1688.00

A - B significant

C - D significant
The analysis of variance disclosed a marginally (0.049) significant interaction between structure (S) and uncertainty (U); this is contrary to H2, which predicted no structure by uncertainty interaction. Also contrary to H2, there were significant differences, for both low and high uncertainty, between the cost of private/leased carriers and the cost of contract carriers (see Figure 9). Under both uncertainty conditions, contract carriers were the more efficient alternative (A - B and C - D both significant). H2 was not supported.

**H3A and H3B**

**H3A:** Over all conditions of uncertainty and asset specificity, when the volume of shipments is low (Vl), the more efficient alternative (measured by mean shipment cost) will be contract carriers (Sc) (Vl has a negative slope).

**H3B:** Over all conditions of uncertainty and asset specificity, when the volume of shipments is high (Vh), the more efficient alternative (measured by mean shipment cost) will be private/leased carriers (Sp) (Vh has a positive slope)

- A - Mean for cells in private/leased carriers (Sp) and low volume (Vl) 2213.73
- B - Mean for cells in contract carriers (Sc) and low volume (Vh) 1761.75
- C - Mean for cells in private/leased carriers (Sp) and high volume (Vh) 1732.25
- D - Mean for cells in contract carriers (Sc) and high volume (Vh) 1618.50

* A - B significant
* C - D not significant
The analysis of variance revealed an interaction between structure (S) and volume (V), which can be noted on Figure 10; The effect of structure on cost depended on the level of shipment volume.

H3A was supported; if the volume of shipments was low, the most efficient alternative was contract carriers (A - B). However, H3B was not supported; although the pattern of cell means suggested that contract carriers were more efficient for a high volume of shipments (the opposite of what was predicted), the result was not significant (see Figure 10).

H4A and H4B

H4A Across all volume conditions, when operational uncertainty is low (Ul) and a shipment can go standard trailers (Al), the more efficient alternative (measured by mean shipment cost) will be contract carriers (Sc) (Al has a negative slope). However, if refrigerated trailers are required (Ah), the more efficient alternative will be private/leased carriers (Sp) (Ah has a positive slope).

H4B Across all volume conditions, when operational uncertainty is high (Uh) and a shipment can go in standard trailers (Al), the more efficient alternative (measured by mean shipment cost) will be contract carriers (Sc) (Al has a negative slope). However, if refrigerated trailers are required (Ah), the more efficient alternative will be private/leased carriers (Sp), and the difference (in mean shipment cost) between private/leased carriers (Sp) versus contract carriers (Sc) will be enhanced under high operational uncertainty (Uh) (compare slope of Ah for H4A and H4B; slope of Ah is more positive for H4B)

A - Mean of cells in private/leased carriers (Sp), shipped in standard trailers (Al), under low uncertainty (Ul) 1792.50

B - Mean of cells in contract carriers (Sc), shipped in standard trailers (Al), under low uncertainty (Ul) 1657.50

C - Mean of cells in private/leased carriers (Sp), shipped in refrigerated trailers (Ah), under low uncertainty (Ul) 2124.95

D - Mean of cells in contract carriers (Sc), shipped in refrigerated trailers (Ah), under low uncertainty (Ul) 1727.00

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E - Mean of cells in private/leased carriers (Sp), shipped in standard trailers (Al), under high uncertainty (Uh) 1841.50

F - Mean of cells in contract carriers (Sc), shipped in standard trailers (Al), under high uncertainty (Uh) 1625.50

G - Mean of cells in private/leased carriers (Sp), shipped in refrigerated trailers (Ah), under high uncertainty (Uh) 2133.00

H - Mean of cells in contract carriers (Sc), shipped in refrigerated trailers (Ah), under high uncertainty (Uh) 1723.50

A - B significant

C - D significant

E - F significant

G - H significant

The results of the analysis of variance indicated, contrary to the prediction of H4A and H4B, that the interaction of structure (S) by asset specificity (A) by uncertainty (U) was not significant. There was no difference in the pattern of the structure (S) by asset specificity (A) interaction under low and high uncertainty (see Figure 11).

H4A predicted that, under low uncertainty: 1) contract carriers would be the more efficient alternative when shipping in standard trailers, and 2) private/leased carriers would be the more efficient alternative when shipping in refrigerated trailers. Although 1) was supported (A - B), 2) was not supported (C - D). In fact, contract carriers were significantly more efficient no matter what type of trailers were required (see Figure 11). Therefore H4A was only partially supported.

H4B predicted that, under high uncertainty: 1) contract carriers would still be the more efficient alternative when shipping in standard trailers, and 2) private/leased carriers would be the more efficient alternative when products required refrigerated trailers. Again, 1) was significant and supported (E - F), but 2) was not supported (G - H). In both cases,
contract carriers were significantly more efficient (see Figure 11). Therefore H4B was only partially supported.

**H5A and H5B**

**H5A:** Across all conditions of operational uncertainty, when the volume of shipments is low (VI), the more efficient alternative (measured by mean shipment cost), for either shipments in standard trailers or shipments in refrigerated trailers (for either Al or Ah), will be contract carriers (Sc) (slopes of Al and Ah are negative).

**H5B:** Across all conditions of operational uncertainty, when the volume of shipments is high (Vh), the more efficient alternative (measured by mean shipment cost), for either shipments in standard trailers or shipments in refrigerated trailers (for either Al or Ah) will be private/leased carriers (Sp) (slopes of Al and Ah are positive)

A - Mean of cells in private/leased carriers (Sp), shipped in standard trailers (Al), with low volume (VI) 2044.00

B - Mean of cells in contract carriers (Sc), shipped in standard trailers, with low volume (VI) 1727.50

C - Mean of cells in private/leased carriers (Sp), shipped in refrigerated trailers (Ah), with low volume (VI) 2383.45

D - Mean of cells in contract carriers (Sc), shipped in refrigerated trailers (Ah), with low volume (VI) 1796.00

E - Mean of cells in private/leased carriers (Sp), shipped in standard trailers (Al), with high volume (Vh) 1590.00

F - Mean of cells in contract carriers (Sc), shipped in standard trailers (Al), with high volume (Vh) 1582.50

G - Mean of cells in private/leased carriers (Sp), shipped in refrigerated trailers (Ah), with high volume (Vh) 1874.50

H - Mean of cells in contract carriers (Sc), shipped in refrigerated trailers (Ah), with high volume (Vh) 1654.50
A - B significant
C - D significant
E - F not significant
G - H significant

The analysis of variance results indicated that the second order structure (S) by asset specificity (A) by volume (V) interaction was marginally significant (0.079); the pattern of the structure (S) by asset specificity (A) interaction was affected by the level of volume (V). Evidence of this second order interaction can be seen in Figure 12.

H5A predicted that the most efficient alternative for a low volume of products shipped in either standard or refrigerated trailers would be contract carriers. This prediction was supported (A - B and C - D). Figure 12 illustrates this result.

H5B predicted that the most efficient alternative for a high volume of products shipped in either standard or refrigerated trailers would be private/leased carriers (E - F and G - H). H5B was not supported. There was no significant difference in the cost of shipping in private/leased carriers and contract carriers for a high volume of shipments going in standard trailers (E - F). For a high volume of products in refrigerated trailers, contract carriers were significantly more efficient (G - H), the opposite of what was predicted (see Figure 12).

H6A and H6B

H6A: Across all asset specificity conditions, when operational uncertainty is low (UI) and shipment volume is low (VI), contract carriers (Sc) are the more efficient alternative (measured by mean shipment cost) (slope of VI is negative). However, if shipment volume is high (Vh), private/leased carriers (Sp) are the more efficient alternative (slope of Vh is positive).
H6B. Across all asset specificity conditions, when operational uncertainty is high (U), and shipment volume is low (VI), contract carriers (Sc) are the more efficient alternative (measured by mean shipment cost) (slope of VI is negative). However, if shipment volume is high (Vh), private/leased carriers (Sp) are the more efficient alternative (slope of Vh is positive; identical pattern to H6A).

A - Mean of cells in private/leased carriers (Sp), with low uncertainty (Ul), and low volume (VI) 2198.95

B - Mean of cells in contract carriers (Sc), with low uncertainty (Ul), and low volume (VI) 1775.50

C - Mean of cells in private/leased carriers (Sp), with low uncertainty (Ul), and high volume (Vh) 1718.50

D - Mean of cells in contract carriers (Sc), with low uncertainty (Ul), and high volume (Vh) 1609.00

E - Mean of cells in private/leased carriers (Sp), with high uncertainty (Uh), and low volume (VI) 2228.50

F - Mean of cells in contract carriers (Sc), with high uncertainty (Uh), and low volume (VI) 1748.00

G - Mean of cells in private/leased carriers (Sp), with high uncertainty (Uh), and high volume (Vh) 1746.00

H - Mean of cells in contract carriers (Sc), with high uncertainty (Uh), and high volume (Vh) 1628.00

A - B significant

C - D significant

E - F significant

G - H significant

The second order interaction of structure (S) by uncertainty (U) by volume (V) was predicted to be nonsignificant; the interaction of structure (S) by volume (V) should not be
affected by the level of uncertainty. The analysis of variance results supported this 
prediction, and Figure 13 demonstrates these results.

However, in a pattern similar to H3, the predictions of H6A and H6B were only 
partially supported. H6A predicted that the most efficient alternative for a low volume of 
shipments under low uncertainty was contract carriers (A - B); this prediction was supported 
(see Figure 13). However, the prediction by H6A of private/leased carriers as the most 
efficient alternative for a high volume of shipments under low uncertainty (C - D) was not 
supported (contract carriers were more efficient (see Figure 13)). Therefore, H6A was only 
partially supported.

The results for H6B were identical to those of H6A; as predicted, increased 
uncertainty did not change the pattern of the structure by volume interaction. For both a 
low and a high volume of shipments, contract carriers were the more efficient alternative 
(E - F and G - H) just as they were under low uncertainty (see Figure 13). H6B was only 
partially supported.

**H7A and H7B**

**H7A:** Under either low (Ul) or high (Uh) operational uncertainty, when shipment 
volume is low (VL), and refrigerated trailers are required (Ah), contract 
 carriers (Sc) are the more efficient alternative (measured by mean shipment 
cost); however, high operational uncertainty (Uh) will diminish the difference 
between the mean shipment cost for contract (Sc) versus private/leased (Sp) 
carriers (slope of Ah is less negative in graph (II) than graph (I) of Figure 4).

When shipments go in standard trailers (Al), high operational uncertainty 
(Uh) causes no diminishment in the difference (in mean shipment cost) for 
contract (Sc) versus private/leased carriers (Sp) (slope of Al is the same for 
graphs (I) and (II) of Figure 4).

**H7B:** Under either low Ul or high (UH) operational uncertainty, when shipment 
volume is high (VH), and refrigerated trailers are required (Ah), private/leased 
carriers (Sp) are the more efficient alternative (measured by mean shipment 
cost); however, under high operational uncertainty (UH), this effect will be 
enhanced, magnifying the difference (in mean shipment cost) for
private/leased (Sp) versus contract (Sc) carriers (slope of Ah is more positive for graph (IV) than graph (III) of Figure 4).

When shipments go in standard trailers (Al), high operational uncertainty (Uh) causes no enhancement in the difference (in mean shipment cost) for contract (Sc) versus private/leased (Sp) carriers (slope of Al is the same for graphs (III) and (IV) of Figure 4)

A - Mean of cell for private/leased carriers (Sp), shipped in refrigerated trailers (Ah), under low uncertainty (Ul), and low volume (Vl) 2387.90

B - Mean of cell for contract carriers (Sc), shipped in refrigerated trailers (Ah), under low uncertainty (Ul), and low volume (Vl) 1808.00

C - Mean of cell for private/leased carriers (Sp), shipped in refrigerated trailers (Ah), under high uncertainty (Uh), and low volume (Vl) 2379.00

D - Mean of cell for contract carriers (Sc), shipped in refrigerated trailers (Ah), under high uncertainty (Uh), and low volume (Vl) 1784.00

E - Mean of cell for private/leased carriers (Sp), shipped in standard trailers (Al), under low uncertainty (Ul), and low volume (Vl) 2010.00

F - Mean of cell for contract carriers (Sc), shipped in standard trailers (Al), under low uncertainty (Ul), and low volume (Vl) 1743.00

G - Mean of cell for private/leased carriers (Sp), shipped in standard trailers (Al), under high uncertainty (Uh), and low volume (Vl) 2078.00

H - Mean of cell for contract carriers (Sc), shipped in standard trailers (Al), under high uncertainty (Uh), and low volume (Vl) 1712.00

i - Mean of cell private/leased carriers (Sp), shipped in refrigerated trailers (Ah), under low uncertainty, and high volume (Vh) 1862.00

J - Mean of cell for contract carriers (Sc), shipped in refrigerated trailers (Ah), under low uncertainty, and high volume (Vh) 1646.00

K - Mean of cell for private/leased carriers (Sp), shipped in refrigerated trailers (Ah), under high uncertainty (Uh), and high volume (Vh) 1887.00

L - Mean of cell for contract carriers (Sc), shipped in refrigerated trailers (Ah), under high uncertainty (Uh), and high volume (Vh) 1663.00

M - Mean of cell for private/leased carriers (Sp), shipped in standard trailers (Al), under low uncertainty (Ul), and high volume (Vh) 1575.00

N - Mean of cell for contract carriers (Sc), shipped in standard trailers (Al),

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under low uncertainty (Ul), and high volume (Vl) 1572.00

O - Mean of cell for private/leased carriers (Sp), shipped in standard trailers (Al), under high uncertainty (Uh), and high volume (Vh) 1605.00

P - Mean of cell for contract carriers (Sc), shipped in standard trailers (Al), under high uncertainty (Uh), and high volume (Vh) 1593.00

A - B significant
C - D significant
E - F significant
G - H significant
I - J significant
K - L significant
M - N nonsignificant
O - P nonsignificant

The analysis of variance results did not support the prediction of the third order interaction of structure (S) by asset specificity (A) by uncertainty (U) by volume (V); in other words, the pattern of the second order interaction of structure (S) by asset specificity (A) by volume (V) (demonstrated in Figure 12) was not affected by the level of uncertainty.

Therefore, the pattern of results exhibited by H7A and H7B is the same as that exhibited by H5A and H5B (compare Figures 14 and 15 (H7A (I) & (III) and H7B (III) & (IV)) with Figure 12 (H5A and H5B)).

H7A predicted that contract carriers would be the more efficient alternative for a low volume of shipments requiring either standard and refrigerated trailers under both low and high uncertainty. This prediction was supported (A - B; C - D; E - F; G - H), as demonstrated in Figure 14.
H7B predicted that private/leased carriers would be the more efficient alternative for a high volume of shipments requiring either standard or refrigerated trailers under both low and high uncertainty. This prediction was not supported, as demonstrated in Figure 15. For a high volume of shipments requiring refrigerated trailers, under both low and high uncertainty, contract carriers were significantly more efficient (I - J and K - L); this is the opposite of what was predicted (see Figure 15). For a high volume of shipments going in standard trailers, there was no significant difference between private/leased carriers and contract carriers (M - N; O - P).

**SUMMARY OF PRINCIPAL FINDINGS**

The interaction of structure and asset specificity predicted by H1A and H1B was supported, but the predicted simple main effects were only partially supported. Shipments requiring standard trailers were more efficient when going in contract carriers as predicted by H1A, but not significantly so. However, shipments requiring refrigerated trailers were also less costly when going in contract carriers, a result opposite of the one predicted by H1B (see Figure 9).

H2 was not supported. The interaction between structure and uncertainty was marginally significant. Furthermore, contract carriers were significantly more efficient under both low and high uncertainty; the prediction was that there would be no difference between the two structures (see Figure 9).

The interaction of structure and volume predicted by H3A and H3B was supported, but the predicted simple main effects were only partially supported. For a low volume of shipments, contract carriers were less costly, as predicted by H3A, but, contrary to H3B, a high volume of shipments was also less costly when shipped in contract carriers, although not significantly so (see Figure 10).
The second order interaction of structure by asset specificity by uncertainty predicted by H4A and H4B was not supported. The simple main effects predicted by H4A and H4B were only partially supported. Shipments requiring standard trailers were less costly when going in contract carriers, as predicted by H4A, but shipments requiring refrigerated trailers were also less costly when going in contract carriers, contrary to the prediction of H4B (see Figure 11).

The second order interaction of structure by asset specificity by volume predicted by H5A and H5B was marginally significant. The results for a low volume of shipments predicted by H5A were supported; contract carriers were the more efficient alternative. However, contract carriers were also the more efficient alternative for a high volume of shipments (although contract carriers were not significantly more efficient for shipments in standard trailers). These results were opposite to those predicted by H5B (see Figure 12).

The second order interaction of structure by uncertainty by volume was not significant, as predicted by H6A and H6B; there was no difference in the interaction of structure by volume for different levels of uncertainty. H6A was only partially supported; for a low volume of shipments, under low uncertainty, contract carriers were more efficient, as predicted. However, for a high volume of shipments, under low uncertainty, contract carriers were also more efficient, contrary to predictions. Likewise, H6B was only partially supported, with the same pattern of results, since there was no second order interaction (see Figure 13).

The third order interaction of structure by asset specificity by uncertainty by volume was not supported. Therefore, the results for the simple main effects predicted by H7A and H7B were identical to the results of H5A and H5B (structure by asset specificity by volume interaction) (compare Figures 14 and 15 with Figure 12).
CHAPTER V
DISCUSSION AND CONCLUSIONS

This study examined the following research problem:

How is the cost of motor carrier transportation affected by how it is structured (performed internally or externally) and the characteristics of the transportation?

Using an alternative methodology and a conceptual framework from transaction cost analysis, the make or buy decision for outbound motor carrier transportation of finished products was investigated. The factors examined in the experimental design (structure, asset specificity, uncertainty, and volume/frequency) were suggested by transaction cost analysis, which has been used extensively in economics, management, and marketing literature to address the make or buy issue for various business functions. Survey methodology has been used for much of the research that uses TCA as a conceptual framework. This methodology lacks the degree of experimental control necessary to explore the combined effects of TCA constructs. The methodology used in this research offered a higher degree of control, since an experimental design was executed on a computer simulation model of an outbound transportation system. Exploration of this particular research problem is managerially relevant in light of the preoccupation with outsourcing transportation services which has developed in the post-deregulation environment of the transportation industry.

This chapter considers the results of the study in light of its conceptual, methodological, and managerial objectives. The next section discusses the results of the research hypotheses. Following that, overall conclusions and implications are addressed. Finally, the last section considers the study’s limitations and offers several recommendations for further research.
HYPOTHESES

The research hypotheses tested by the experimental design used in this study were designed to answer the following research questions:

1) Is the relative efficiency of outsourced transportation versus transportation by private fleet affected by the type of carrier equipment required for the transportation activities?

2) Is the relative efficiency of outsourced transportation versus transportation by private fleet affected by operational uncertainty (e.g., delays along transportation routes due to weather, road conditions, or labor unrest)?

3) Is the relative efficiency of outsourced transportation versus transportation by private fleet affected by the volume of products that are transported?

4) What is the combined effect of equipment requirements, operational uncertainty, and volume transported on the relative efficiency of outsourced transportation versus transportation by private fleet.

In order to answer these questions, the research hypotheses, facilitated by a full factorial experimental design, focused on the exploration of interaction effects, as well as the accompanying simple main effects, for the four independent variables of structure, asset specificity, uncertainty, and volume. The results of each of the research hypotheses are discussed below.

HYPOTHESES 1A AND 1B

H1A Over all conditions of uncertainty and volume, the more efficient alternative (measured by mean shipment cost) for shipments requiring standard trailers will be contract carriers. **NOT SUPPORTED**

H1B Over all conditions of uncertainty and volume, the more efficient alternative (measured by mean shipment cost) for shipments requiring refrigerated trailers will be private/leased carriers. **NOT SUPPORTED**

The interaction of structure and asset specificity was supported by the analysis of variance, but the predicted simple main effects were not supported. TCA maintains that, when specific assets are not required, it may be more efficient to "buy" than to "make".

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Although the results were in the predicted direction, "buying" was not significantly more efficient than "making" for shipments going in standard trailers.

On the other hand, when specific assets are required, TCA predicts that it is more efficient to "make" than to "buy". The results were opposite of those predicted by TCA; "buying" or contract carriers were more efficient even when refrigerated carriers were required.

There appear to be two reasons for these results. The lack of significance in the data for shipments in standard trailers is probably due to the lack of power of the Scheffe S test. The test statistic for the contrast of this group of cells was very close to being significant, as well as being in the predicted direction.

The lack of support for the predictions about shipments in refrigerated trailers is caused by the apparent lack of a "small numbers bargaining" situation where refrigerated carriers are concerned. Although, in the system modelled here, there were increased costs involved in transacting, or contracting for shipments, there was no indication that these costs were higher when contracting for refrigerated carriers versus contracting for standard dry freight carriers. The significant increase in the number of carrier firms following deregulation has apparently resulted in a balancing of supply and demand, and a corresponding lack of a market failure situation, at least for refrigerated carriers.

**HYPOTHESIS 2**

H2 Over all conditions of asset specificity and volume, there will be no significant difference between the mean cost of shipments in private/leased carriers and the mean cost of shipments in contract carriers; this will be true no matter what the level of operational uncertainty is. **NOT SUPPORTED**

TCA maintains that uncertainty has little effect on the make or buy decision unless it is combined with market failure, i.e., the small numbers bargaining situation that specific
assets may precipitate. Therefore, there should be no interaction between structure and uncertainty. Furthermore, since predicted higher order interactions (H3, H4, H5, and H6) might be expected to obscure or confound a main effect of structure, this hypothesis predicted no significant difference between the mean cost of shipments in contract versus private/leased carriers.

Neither of these predictions was supported. There was a marginally significant interaction of structure and uncertainty, and contract carriers were significantly more efficient, with or without the presence of operational uncertainty.

The unexpected interaction between structure and uncertainty occurred because, when operational uncertainty caused unpredictable delivery for shipments going in private/leased carriers, the shipping firm spent significant amounts of time tracing these shipments. However, when operational uncertainty caused unpredictable delivery of shipments going in contract carriers, the shipping firm’s contract with the carrier put the responsibility for tracing shipments on the carrier. Therefore, for the system represented in this research, operational uncertainty resulted in measurably increased costs only for shipments going in private/leased carriers.

It could be argued that there may be hidden (transaction) costs involved when dealing with contract carriers in situations involving operational uncertainty. Information from both companies that provided the majority of the cost data for this research indicated that contracting with numerous carriers was, in fact, quite expensive in terms of management/staff time (Peterson 1994b; Stewart 1994b). Certainly, a portion of these costs involves determining a carrier’s shipment tracing capabilities, perhaps as part of an

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5 For example, when selecting carriers, resources may be spent to ascertain the technological sophistication of a carrier’s shipment tracking capabilities, for instance, satellite tracking capabilities (Peterson 1994a).
investigation of the carrier's customer service record. However, in the system modeled for
this research, even when expenses for management/clerical salaries under the contract
carrier structure (Sc) were increased, the percentage of total costs accounted for by these
transaction costs was so small\(^6\) that the increased transaction costs were consistently
overshadowed by the lower transportation costs (TL freight rates) for contract carrier
shipments.

This result (contract carriers were more efficient than private/leased carriers) was
exhibited by the majority of the hypotheses and is demonstrated by the large effect size for
structure (note the \(\eta^2\) statistics for effect size in Table 18). The strong main effect for
structure can be explained by two factors:

1) Transportation is a carrier firm's core business. As a result, carrier firms are
simply better at transportation than a firm who does not view transportation
as vital to its mission. For instance, they may be more willing to invest in
new technology (e.g., satellite tracking systems).

2) The post de-regulation competitive environment has forced carriers to
compete effectively or be forced out of business. Therefore, the firms that
remain in business tend to be very effective at transportation.

The strong effect of structure in this research illustrates an important issue. When
considering variables which impact make or buy decisions, factors in the "supplying"
industry (in this case, the motor carrier transportation industry) may exaggerate the
influence of certain variables (this point is discussed further in this chapter under Asset
Specificity).

\(^6\) See Table 17, which contains the percentage of total shipping costs accounted for by
transaction costs for each treatment cell. The largest percentage of total shipping costs
accounted for by transaction costs is 13.1\%.
HYPOTHESES 3A AND 3B

H3A  Over all conditions of uncertainty and asset specificity, when the volume of shipments is low, the more efficient alternative (measured by mean shipment cost) will be contract carriers. SUPPORTED

H3B  Over all conditions of uncertainty and asset specificity, when the volume of shipments is high, the more efficient alternative (measured by mean shipment cost) will be private/leased carriers. NOT SUPPORTED

The structure by volume interaction predicted by this set of hypotheses was significant, but, predictions for the pattern of simple main effects were only partially supported. TCA predicts that "buying" will be more efficient for relatively infrequent transactions. This prediction was supported.

However, for a high volume of shipments (contrary to what was predicted) private/leased carriers were not more efficient. The pattern of cell means suggested that contract carriers were more efficient, although not significantly so.7

The prediction of private/leased carriers as more efficient for a high volume of shipments was based on the assumption that a firm operating private/leased carriers could generate enough volume to realize significant economies of scale. However, the per mile operating cost of outbound transportation for a private/leased fleet depends primarily on the ability to reduce or eliminate empty backhaul miles. For the system modeled in this research, even when empty backhaul miles were at a minimum (approximately 6% of shipments returning empty), the private/leased fleet was not able to enjoy economies of scale sufficient to make it more efficient than shipping in contract carriers (hence the lack of support for H3B). The post-deregulation competitive environment has increased the cost

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7 The scale economies generated by the high volume of shipments in private/leased carriers reduced the advantage of contract carriers over private/leased carriers. On the other hand, the lack of scale economies for a low volume shipped in private/leased carriers enhanced the advantage of contract carriers; hence the interaction of structure and volume.
efficiency of surviving carrier firms to the point that, at least in the case of the system modeled here, continued operation of a private/leased fleet would constitute a very poor business decision. The generalizability of this result, along with suggestions for further exploration of this issue, are discussed later in this chapter, under Asset Specificity.

HYPOTHESES 4A AND 4B

H4A Across all volume conditions, when operational uncertainty is low, and shipments can go in standard trailers, the more efficient alternative (measured by mean shipment cost) will be contract carriers. However, if refrigerated trailers are required, the more efficient alternative will be private/leased carriers. PARTIALLY SUPPORTED.

H4B Across all volume conditions, when operational uncertainty is high, and shipments can go in standard trailers, the more efficient alternative (measured by mean shipment cost) will be contract carriers. However, if refrigerated trailers are required, the more efficient alternative will be private/leased carriers, and the difference (in mean shipment cost) between private/leased carriers versus contract carriers will be enhanced under the high operational uncertainty condition. PARTIALLY SUPPORTED.

TCA maintains that, when requirements for specific assets are combined with uncertainty, it may be more efficient to make rather than buy. Based on this, it was predicted that the pattern of the structure by asset specificity interaction would change, depending on whether uncertainty was low or high. However, this second order interaction was not supported. The structure by asset specificity interaction was the same under both low and high uncertainty conditions, exhibiting the same pattern of simple main effects as in hypothesis 1A and 1B.

The reason for the lack of effect for uncertainty is due to the lack of consistently increased costs in the face of uncertainty across both levels of structure; operational uncertainty caused increased costs for shipments going in private/leased carriers, but not for shipments going in contract carriers (see discussion of results for H2).
HYPOTHESES 5A AND 5B

H5A: Across all conditions of operational uncertainty, when the volume of shipments is low, the more efficient alternative (measured by mean shipment cost), for either shipments in standard trailers or shipments in refrigerated trailers, will be contract carriers. SUPPORTED.

H5B: Across all conditions of operational uncertainty, when the volume of shipments is high, the more efficient alternative (measured by mean shipment cost), for either shipments in standard trailers or shipments in refrigerated trailers will be private/leased carriers. NOT SUPPORTED.

Hypotheses 5A and 5B attempted to predict the pattern of results when the increased transaction costs caused by requirements for specific assets were combined with the effects of volume (scale economies). A second order interaction was predicted for structure by asset specificity by volume; i.e., the structure by asset specificity interaction was expected to behave somewhat differently, depending on the level of volume. The prediction of this second order interaction was based primarily on the assumption that the effects of scale economies (high volume) would tend to obscure, to some extent, the effects of specific asset requirements.

Results for this set of hypotheses indicated that the second order interaction was marginally significant, but the predicted simple main effects were only partially supported.

For a low volume of shipments, contract carriers were predicted to be the more efficient alternative. This prediction was supported; when shipment volume was low, contract carriers were significantly less expensive, no matter whether standard or refrigerated trailers were required (H5A). However, for the system modeled here, the reason for this result does not appear to involve any balancing of transaction costs due to specific asset requirements with scale economies; it was simply the result of the low volume being unable to generate scale economies for private/leased carriers.

For a high volume of shipments requiring refrigerated trailers, H5B predicted that transaction costs would make contract carriers more expensive than private/leased carriers.
It was hypothesized that scale economies caused by the high volume of shipments would make the private/leased carriers efficient; in addition, transaction costs would be lower for private/leased shipments, further enhancing their efficiency. For a high volume of shipments that could be shipped in standard trailers, scale economies would make the private/leased carriers competitive with contract carriers.

Neither of these predictions was supported; for a high volume of shipments, contract shipments were the more efficient alternative for shipments in refrigerated trailers; the difference between private/leased and contract carriers for standard trailers was not significant. The reason for the lack of significance for shipments in standard trailers appears to be because the scale economies of the higher shipment volume, combined with the lower costs of leasing standard trailer equipment make the difference between private/leased and contract shipments less distinct.

The pattern of results for this set of hypotheses is due to the lack of market failure for the operationalization of specific assets in this research (refrigerated trailers). The large effects of structure (see discussion of results for H1B) and volume (see discussion under HYPOTHESES 3A AND 3B) appeared to overshadow the effects for the remaining factors (see Table 18 for the $\eta^2$ statistics). This issue is discussed further under OBJECTIVES OF THE RESEARCH and Asset Specificity.

**HYPOTHESES 6A AND 6B**

H6A Across all asset specificity conditions, when operational uncertainty is low and shipment volume is low, contract carriers are the more efficient alternative (measured by mean shipment cost). However, if shipment volume is high, private/leased carriers are the more efficient alternative. **PARTIALLY SUPPORTED.**

H6B Across all asset specificity conditions, when operational uncertainty is high, and shipment volume is low, contract carriers are the more efficient alternative (measured by mean shipment cost). However, if shipment
volume is high, private/leased carriers are the more efficient alternative.

PARTIALLY SUPPORTED.

As predicted, there was no second order structure by uncertainty by volume interaction; the pattern of the interaction of structure by volume did not differ with the level of uncertainty. Therefore, as hypothesized, the results of H6A and H6B are the same, and identical to H3A and H3B (compare Figure 10 and Figure 13; in Figure 13, the graphs for the Ul and Uh conditions are identical).

As predicted by H6A and H6B, contract carriers were more efficient for a low volume of shipments. However, contrary to hypotheses H6A and H6B, contract carriers (not private/leased carriers) were also more efficient for a high volume of shipments. Since the prediction for a low volume of shipments was supported, but not the prediction for a high volume of shipments, both hypotheses 6A and 6B were only partially supported.

These results are further evidence of the large effect of volume in the system modelled here.

HYPOTHESES 7A AND 7B

H7A Under either low or high operational uncertainty, when shipment volume is low, and refrigerated trailers are required, contract carriers are the more efficient alternative (measured by mean shipment cost); however, high operational uncertainty will diminish the difference between the mean shipment cost for contract versus private/leased carriers. NOT SUPPORTED.

When shipments go in standard trailers, high operational uncertainty causes no diminishment in the difference between the difference (in mean shipment cost) for contract versus private/leased carriers. SUPPORTED.

H7B Under either low or high operational uncertainty, when shipment volume is high, and refrigerated trailers are required, private/leased carriers are the more efficient alternative (measured by mean shipment cost); however, under high operational uncertainty this effect will be enhanced, magnifying the difference (in mean shipment cost) for private/leased versus contract carriers. NOT SUPPORTED.
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*** Large Effect
* Small Effect (Pedhazur and Schmelkin 1991)
When shipments go in standard trailers, high operational uncertainty causes no enhancement in the difference (in mean shipment cost) for contract versus private/leased carriers. **NOT SUPPORTED.**

The third order interaction of structure by asset specificity by uncertainty by volume was not significant, implying that the pattern of the second order interaction of structure by asset specificity by volume is not affected by the level of uncertainty. Therefore, H7A and H7B exhibit the same second order interaction of structure by asset specificity by volume exhibited by H5A and H5B. The results for the simple main effects for H7A and H7B are also similar to the results for the simple main effects for H5A and H5B; increased volume reduced the advantage of contract carriers over private/leased carriers.

This set of hypotheses predicted that, when shipments required refrigerated carriers, increased levels of operational uncertainty would increase transaction costs, thereby making these shipments more expensive. Since the system modeled for this research did not appear to be susceptible to increased transaction costs when refrigerated trailers were required (see discussion of results of H1B), the interaction predicted by this set of hypotheses was not supported.

**CONCLUSIONS AND IMPLICATIONS**

This section presents the major conclusions and implications of the results of this study. The first section discusses implications of the research in light of the study’s objectives. The second section discusses the results of some additional analyses of the transportation system modeled in this research.
OBJECTIVES OF THE RESEARCH

The objective of this research was to investigate the make or buy decision for motor carrier transportation of finished products. In an effort to understand the complex interaction of factors that drives a make or buy decision, this study went beyond simply surveying what structure (make or buy) a firm chooses to accomplish the performance of an activity. The experimental design used variables suggested by transaction cost analysis and utilized a hypothesis testing approach to examine a logistics research problem.

The methodology used facilitated exploration of the factors that (according to TCA) drive the make or buy decision. Where the predictions of the research were supported, the methodology encouraged a more thorough understanding of the factors and interactions driving the make or buy decision. Where the predictions of the research were not supported, the methodology facilitated both the explanation of the lack of support, as well as delineation of further research to investigate the lack of support.

Designation of mean shipment cost as a dependent variable and the inclusion of transaction costs (e.g., fleet management, shipment tracing, customer service monitoring, and carrier selection and contracting costs) in this mean shipment cost facilitated the examination of the total cost implications of make or buy decisions. Furthermore, the use of an experimental design enabled this research to quantify (within a controlled setting) the effects of the independent variables on mean shipment cost. Exploration of the total cost implications of the TCA framework has important theoretical implications, since from the standpoint of internal validity, exploration of the TCA theoretical framework is deficient without generating hypotheses and attempting to obtain empirical support for the normative performance implications implied by the framework. Exploration of total cost implications also has significant managerial ramifications; the usefulness of including the factors
suggested by TCA in managerial make or buy decisions is largely determined by whether or not these factors will meaningfully affect performance.

In general, the results of the seven sets of research hypotheses are strongly supportive of the TCA paradigm. The competitiveness of the post deregulation transportation industry keeps freight rates relatively low, while effectively preventing small numbers bargaining situations from developing.

Because of the intensely competitive nature of this "supplying" industry, structure and volume were the factors having the largest effect on mean shipment cost (see Table 18). The explanation for the large effect of structure in the transportation system modelled here follows the rationale of Mallen's (1973) functional spin-off argument. Transportation is a carrier firm's core business; as a result, carrier firms are simply better at transportation (for instance, perhaps more willing to invest in new technologies) than a firm which does not view transportation as vital to its mission. The post de-regulation competitive environment probably enhances this effect by making it imperative for carriers to compete effectively or be forced out of business.

The large effect demonstrated by volume is due to economies of scale being such a strong driver of cost reduction. Predictions for the superior efficiency of contract carriers over private/leased carriers for a low volume of shipments (which were uniformly supported) were based on these scale economies effects. In addition, the results for H3A and H3B; H5A and H5B; H6A and H6B; and H7A and H7B all demonstrate that, although contract carriers were the more efficient alternative, a high volume of shipments reduced the advantage of contract carriers over private/leased carriers (note the difference in the pattern for the VI and Vh graphs for private/leased (Sp) and contract (Sc) in Figures 10, 12, 13, 14 and 15).
Asset specificity also had a large effect, presumably due to increased equipment expenses (e.g., leasing and operating expenses) incurred when operating refrigerated trailers. The two first order interactions of structure by volume and structure by asset specificity also had large effects. The advantage of contract carriers over private/leased carriers was reduced when there was a large volume of shipments (see Figure 10; the difference between private/leased (Sp) and contract (Sc) is not significant for high volume (Vh)). The cost advantage of contract carriers over private/leased carriers was greater for shipments requiring refrigerated trailers (see Figure 12; in both the graphs (H5A and H5B), the cost advantage of contract (Sc) over private/leased (Sp) is more pronounced in the case of refrigerated trailers (Ah)).

ADDITIONAL ANALYSES OF THE TRANSPORTATION SYSTEM

Interviews with the companies that provided the majority of the cost data for this research indicated that the managers felt that the highest "transaction" costs were incurred in contracting with a large number of TL carriers. However, they also maintained that the transaction costs of operating a private/leased fleet were substantial. In an effort to minimize these costs, as well as to receive even lower per mile TL freight rates, both companies are in the process of decreasing the number of carriers with which they contract their transportation (Peterson 1994b; Stewart 1993).

The firm whose transportation system was used for the model in this research (company H) has a relatively low volume of shipments. Their solution to the problem of contracting with numerous carriers is to work toward turning all of their TL freight business to one carrier firm (company B). By doing this, company H will be able to reduce the time spent contracting with numerous carriers. In addition, since company B will transport all of company H's shipments, and since company B utilizes intermodal (a combination of motor
carrier and railroad transportation, company H will be able to obtain discounted rates for the shipments transported by company B (Stewart 1993, 1994b).

Although it was not part of the experimental design, the mean shipment cost for private/leased, contract, and third party (single carrier) shipments was generated by the model and appears in Table 19. The mean cost for the shipments transported by company B (third party shipments) is lower than either of the other two. The fact that company H plans to engage in a contractual relationship with company B, at first glance, appears to contradict TCA predictions. However, Company H’s behavior is, in fact, completely consistent with TCA predictions. The type of trailer required for the transportation of the products company H ships is not specialized, therefore, a “market” arrangement, i.e., contracting with numerous carriers, is predicted by TCA as the efficient arrangement (see the buy/market square in Table 3). Company H’s relationship with company B as their sole provider of transportation and related logistics services is based on yearly contract renewals. Company H has the option of replacing company B if their price and service are not satisfactory. The competitiveness inherent in the post de-regulation transportation industry and Company H’s lack requirements for specific assets (i.e., specialized carriers) means there is a large number of carriers available for Company H to contract with, which prevents Company B from behaving opportunistically.

The distribution manager of company H felt that the reallocation of resources from either private/leased fleet operations or contracting with numerous TL carriers, to maintaining a relationship with one transportation provider (company B) would be more strategically productive for the firm. Evidence of this is provided by the fact that company H’s distribution system (e.g., warehousing facility locations, manufacturing site locations) is in the process of being completely re-evaluated. The resources required for this re-evaluation (especially management resources) would not be as readily available if they
TABLE 19  COMPARISON OF MEAN TOTAL SHIPMENT COST FOR PRIVATE/LEASED, CONTRACT, AND THIRD PARTY SHIPMENTS

<table>
<thead>
<tr>
<th></th>
<th>PRIVATE/LEASED SHIPMENTS</th>
<th>CONTRACT SHIPMENTS</th>
<th>THIRD PARTY SHIPMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEAN TOTAL SHIPMENT COST</td>
<td>$2010.00*</td>
<td>$1743.00*</td>
<td>$1519.00*</td>
</tr>
</tbody>
</table>

* based on a set of three t-tests; p < 0.016.
were still being spent on private/leased fleet management or managing contracts with numerous carriers (Stewart 1993, 1994a, 1994b).

A similar viewpoint was echoed by the inventory planning and control manager of company P, the manufacturer of grocery products requiring refrigerated shipments. In moving from a private/leased fleet to contracting with numerous contract carrier firms (at one time, more than 100), and finally to contracting with gradually fewer carriers, he feels that the company will be able to focus resources on activities that are strategically more productive for the company (Peterson 1994a, 1994b).

Contracting with few or only one carrier appears to have two potential advantages for company H: 1) it reduces the relatively high transaction costs incurred by maintaining numerous carrier contracts, and 2) it enhances the advantages of the "buy" structure (Sc) demonstrated by the results of the hypotheses tests in this study, especially for companies with a low volume of shipments (by contracting with fewer carriers, a shipper's volume is more concentrated, perhaps qualifying shipments for volume discounts). The advantages demonstrated in this research of these "exclusive" relationships with carrier firms, as pointed out above, are completely supportive of TCA predictions, given the high level of competition in the transportation industry. Furthermore, these results provide validation for the current interest in relationship marketing research.

**LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH**

CHAPTER I provided an extensive discussion of the limitations inherent in computer simulations. These limitations will be reviewed briefly here, along with their implications in light of the objectives of this study. The final portion of this section discusses suggestions for future research.
LIMITATIONS OF SIMULATION MODELLING

One potential limitation of computer simulations is the difficulty of constructing a valid model of the system being studied. Modelling a system represents a trade-off between realism and simplicity. The factors represented and the level of detail for the transportation system model constructed for this research were guided by: 1) the theoretical framework chosen for the investigation of the research problem and 2) the level of detail necessary for the investigation of the specific research questions. The results of validation procedures in Chapter IV provided an estimate of how well the model conformed to the system it represented.

While the validation results in Chapter IV provided some evidence of representativeness, this representativeness cannot be assumed for the full range of system conditions, nor can it be assumed to validly depict the transportation situations faced by all firms. However, although the simulation model constructed for this research cannot be representative of all transportation systems, generalizability was not the principal goal of this research. The goal of this study was to use a research method that addressed some of the drawbacks inherent in the descriptive methodology used in most of the existing research on the make or buy issue. The previous section discussed the advantages of the experimental control afforded by the methodology used in this research.

Another potential limitation of simulation modelling pertains to the analysis of the data generated by a simulation model. Analysis of variance, which was used to analyze the data generated by the model, assumes that: 1) the samples are independent, 2) the population(s) from which the samples are drawn are normally distributed, 3) the variance of the populations are equal. Independence of samples for the simulation data in this research was maintained by the use of independent simulation replications (independent generation of random number streams among samples and across cell treatments). Furthermore, each cell
in the experimental design contained an equal sample size (n = 10), reducing the sensitivity of the F-test (in the analysis of variance) to potential departures from normality and homogeneity of variance (Scheffe 1959).

SUGGESTIONS FOR FUTURE RESEARCH

As Table 18 demonstrates, the power to detect several of the proposed interactions (Structure by Asset Specificity by Uncertainty; Structure by Uncertainty by Volume; Structure by Asset Specificity by Uncertainty by Volume) was somewhat low. The primary reason for this decreased power was the small effect sizes exhibited by these interactions. One way to address this limitation and increase the power to detect these effects would be to perform the experimental analysis of this study's transportation system using a larger cell size.

The principal limitation of this research was that the hypotheses which predicted the market failure effects of asset specificity (and asset specificity combined with uncertainty) were not supported. The first part of this section addresses this issue; the second part of this section discusses some possible extensions of this study.

Asset Specificity

There could be several reasons for the lack of support for the asset specificity and uncertainty hypotheses:

1) The model was not a valid representation of the system being simulated.

2) In a post deregulation transportation environment, the cost savings driven by economies of scale will always overwhelm transaction costs.

3) The role of measurement error, specifically with regard to how transaction costs were measured.
4) The operationalization used in this research to represent the asset specificity condition (refrigerated trailers) lacked sufficient strength.

The first possible explanation, model invalidity, although always a concern with modeling methodology, is unlikely to be the reason for the lack of support for the hypotheses. Model verification demonstrated that the model performed as it was intended. The model’s face validity was monitored by using cost data from people knowledgeable with a similar system. Finally, at least for certain conditions, validation procedures demonstrated that the model was a reasonable representation of the system being modeled.

The second explanation, the overwhelming effects of economies of scale, could be responsible for the lack of support for the asset specificity/uncertainty research hypotheses. However, whether this explanation is reasonable implies an investigation of the generalizability of the effects of economies of scale with respect to transportation services. To explore the generalizability of this explanation, a research methodology which stresses generalizability (e.g., a mail survey) would have to be used. For instance, a survey of transportation and/or distribution managers, to determine the type of carriers required, the structure employed (private/leased versus outsourced), and the mean shipment cost is one possible way to explore the strength of the effects of scale economies versus transacting costs within the context of transportation services.

Measurement error with regard to the measurement of transaction costs could be an explanation for the lack of results for the asset specificity/uncertainty hypotheses, especially if the asset specificity which drives the transaction costs is site specific asset specificity or human asset specificity, instead of the physical asset specificity represented in this research. Although site specific asset specificity (e.g., terminals for consolidating shipments) would be relevant for less than truckload (LTL) shipments, the transportation system represented in this research involved only truckload (TL) shipments. For TL
shipments, terminals for consolidating shipments are a relatively minor consideration, therefore, representing asset specificity as site specific assets probably not relevant to the system modeled in this research. However, if the system modeled in this research was extended to encompass LTL, as well as TL shipments, representing asset specificity by the existence of terminals for consolidating shipments could be an important addition to the model.

The information collected during the construction the transportation system modeled for this research did not indicate a significant role for human asset specificity, e.g., specialized driving skills needed for particular types of products. However, human asset specificity could be represented as the specialized knowledge acquired by carrier firms when negotiating for and dispensing transportation services to shippers during year long exclusive transportation contracts. Particularly in light of a motivation to reduce the costs of negotiating with large numbers of carriers (see discussion under ADDITIONAL ANALYSES OF THE TRANSPORTATION SYSTEM), this representation of asset specificity could be an important extension to this research.

The fourth explanation, a lack of strength for the operationalization of asset specificity, seems the most likely explanation for the lack of support for the research hypotheses. At least for the system modelled here, there did not appear to be a market failure condition for refrigerated carrier assets; these assets lacked the necessary degree of specificity, in spite of the fact that their numbers were substantially fewer. A stronger operationalization of specific assets in the transportation model, for instance, might involve the activities and costs required for transporting a product in a specially constructed trailer (e.g., hazardous materials trailers).

One issue, which is highlighted by the asset specificity operationalization issue, is the need for exploration into the nature of the industry providing the outsourced activities.
The results of this research indicated that the intensely competitive nature of the transportation industry may have exaggerated the effects of structure and volume/frequency on efficiency. Research on the make or buy decision generally focuses on the firm doing the making or buying. The results of this study indicate that there may be important factors within the nature of the "supplying" industry that impact the potential buyer’s decision. Some suggestions for factors to investigate in order to explore this issue include: the level of competition, the degree of government regulation, and/or the maturity of the supplying industry. Overall, the results of this research provided strong support for TCA predictions and clearly demonstrated that TCA is a useful framework for understanding firms’ make or buy decisions. Because of the nature of the transportation industry (the high level of competition and the lack of a small numbers bargaining situation), the hypotheses in this research clearly indicated that a "buy" rather than a "make" decision was the most efficient alternative; this result is exactly consistent with TCA predictions.

**Extensions of the Present Study**

Interviews with the representatives of Company H and Company P and the additional analyses of the transportation system in this study demonstrated the motivation to reduce transaction costs by decreasing the number of transportation firms that a shipper negotiates with. Therefore, it might be interesting to use the number of transportation firms a shipper negotiates with as an independent variable and observe the effects on the system as this variable is manipulated.

This research only investigated outbound transportation. Information from the distribution manager and the inventory control manager interviewed for this study reinforced the concept that the make or buy decision for outbound transportation was strategically linked with decisions about other distribution activities. For example, facility location,
materials management, and inventory decisions for multiple echelons of a distribution
system were inevitably linked with the make or buy decision for both inbound and outbound
transportation. Expanding the model to include elements of these other decision areas
would enable a more balanced view of the transportation decision. For instance, given the
importance that the location of a shipment’s destination (e.g., NE, SW) plays in determining
TL freight rates, adding additional echelons (manufacturer to distribution warehouse and
distribution warehouse to customer) to the distribution system modeled here would facilitate
exploration of the effects of facility location decisions on transportation decisions.

Finally, although this study clearly demonstrated support for TCA and its role in
delineating the factors that drive a firm’s decision to enter into and/or sustain a relationship
with another organization, there are undoubtedly other factors that drive this decision.
Within the larger context of relationship marketing research, it would be worthwhile to
explore the role TCA constructs play in conjunction with other key contributors to initiation
and maintenance of relationships with other organizations.
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