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AN EXPERIMENTAL INVESTIGATION OF THE
ORDER CONSOLIDATION PROBLEM

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By
George Charter Jackson, B.S., M.B.A.

* * * * *

The Ohio State University
1979

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I. INTRODUCTION

Many business firms, especially those marketing packaged consumer goods, must ship large numbers of small orders to their customers. Small shipments have become a nagging if not critical problem for many shippers in recent years as pressures to ship in larger quantities have increased at the same time pressures on customers to order in small quantities have also increased. Thus, shippers are caught between two opposing forces: one calls for large shipments while the other produces smaller shipments.

The pressures for larger shipments spring primarily from rising freight costs and deteriorating service for small shipments. Although freight costs to shippers in general have been rising due in large part to increasing fuel and labor costs, rates on less-than-truckload (LTL) freight have outpaced rates covering the more fuel and labor efficient truckload (TL) freight by a significant margin. Thus, the spread between TL and LTL freight rates has been growing and increasing the economic attractiveness of larger shipments relative to small shipments.

In addition to a disproportionate increase in transportation costs for small shipments, there is evidence that there has been a general decline in service levels on LTL freight by carriers wishing to discourage small shipments which are considered to be uneconomical. Reduced service levels result in longer and more erratic transit times for small shipments and poor service can produce tensions between a shipper and his customers.
Small shipments are also more likely than large shipments to be lost or damaged.\(^3\)

Thus, in recent years the growing spread between TL and LTL freight rates and the poorer level of service given to small shipments has provided an incentive for shippers to ship in larger quantities.

The pressures on customers to order in smaller quantities are several. The proliferation of products and styles\(^4\) and the technology of miniaturization have been two phenomena which have worked to decrease shipment size.\(^5\) Another factor has been the tendency for retailers and wholesalers to carry smaller and smaller inventories by requiring their suppliers to react quickly to smaller, more frequently placed orders.\(^6\) This phenomenon is intensified during times of recession and during periods of capital shortage and high interest rates when pressures become great for everyone in the channel, including the shipper, to reduce their inventory investment.\(^7\)

Business firms which ship in small quantities are therefore faced with increased transportation costs coupled with deteriorating service while at the same time customers are ordering increasingly in smaller quantities.

**Small Shipment Strategies**

There are three basic distribution strategies which are employed by business firms to handle small shipments. The basic strategies are (1) less-than-truckload (LTL)\(^8\) shipments directly from the plant warehouse to the customer, (2) field warehousing where the product is shipped in volume to a warehouse in anticipation of demand and (3) order
consolidation, whereby less-than-volume orders destined for the same geographic area are combined to form volume, intercity shipments to a centrally located breakbulk point in that area. From the breakbulk point they are distributed in less-than-volume quantities to their final customer destinations.

Order consolidation compared to LTL direct has certain advantages and disadvantages. The primary advantage is that order consolidation can result in lower transportation costs than shipping LTL direct. These savings result from the fact that there are economies of scale in transportation operations and therefore small, less-than-volume shipments cost the shipper more per unit to transport than do large volume shipments. Unfortunately, cost savings may be secured by increasing the length and variability of the order cycle thereby downgrading the customer service level. The customer service level may suffer because consolidation is achieved by accumulating orders over a period of time which may vary depending on the uncertain time of arrival and size of incoming orders. However, order consolidation offers faster transit times which may offset the time required to consolidate the orders and fewer handlings which produce lower risk of loss and damage. The disadvantage of order consolidation, besides possibly increasing the length and variability of the order cycle, is the administrative effort required to plan, operate and maintain an order consolidation system. This administrative effort can be considerable when compared to shipping LTL direct.
Field warehousing, compared to order consolidation, produces shorter order cycle times but results in higher inventory carrying costs, higher shipping costs at short distances from the plant and extensive administrative efforts. The disadvantage of order consolidation may be the order accumulation period necessary to combine orders for shipment.

For the shipper faced with rising transportation and inventory costs, declining service and increasing numbers of small shipments, order consolidation offers advantages over both LTL direct and field warehousing. Order consolidation, by increasing the size of shipments, can reduce the transportation costs and increase the level of transportation service which would be experienced with an LTL direct system. Thus, a shipper would be better able to cope with smaller customer orders and declining transportation service levels. Order consolidation offers the firm employing a field warehousing system the opportunity to reduce its level of inventory investment.

The Order Consolidation Problem

The challenge in designing an order consolidation system is to reduce transportation and inventory costs without unreasonably damaging the customer service level of the existing system. In the design of an order consolidation system there are three major decision areas: 1) choosing the number and location of breakbulk points to be included in the system 2) establishing the maximum number of days orders can be held to achieve consolidation and 3) whether or not to use stop-offs. The term stop-offs refers to stopping in transit to partially load or unload. Stop offs allow the shipper to consolidate shipments to separate
geographic points. The research reported here focuses on these three important decision areas.

These three decisions are central to the design and operation of an order consolidation system and they are highly interrelated as the following discussion will reveal.

The Number of Breakbulk Points

The first step in designing an order consolidation system is to geographically identify concentrations of demand for less-than-volume orders which can be consolidated in a predetermined amount of time and be delivered at a cost less than shipping LTL direct. Once a breakbulk point is chosen, only those customer destinations are included which can be reached most inexpensively through that point and provide an acceptable customer service level. In other words, the TL freight rate plus the handling charge at the consolidation point and the local transportation charge from the breakbulk point to the final destination must be less than the direct LTL charge. Generally, as distance from the pool point to the customer increases, consolidation becomes less attractive because the LTL freight rate from the breakbulk point to the destination increases at the expense of the savings in the volume line-haul transportation rate made possible by order consolidation. In addition, the order cycle time must not be unreasonably lengthened or made more variable by the consolidation procedure.

Geographic clusters of demand will be identified which will vary from very large volume to very low volume. The very large volume clusters located long distances from the origin offer the greatest
savings and will be readily included in a consolidation system as breakbulk points. The very low volume clusters located near the origin which can be served more economically with direct shipments will just as readily be deleted from a consolidation system. 17 Those clusters receiving moderate volumes of product will be more difficult to evaluate due, perhaps, to modest cost savings but most importantly to the length of time orders might be delayed by the firm during the process of collecting orders into a volume shipment. 18 Therefore, as the number of breakbulk points increases total cost savings can be expected to increase, but at the cost of deteriorating service levels.

Holding Time

The importance of the temporal aspect of order consolidation cannot be underestimated since it has been shown that a supplier's order cycle is an important performance criterion often used by customers to evaluate their suppliers. 19 Furthermore, the variability of the order cycle has been shown to be more important than its length. 20 Other studies have found that in many cases the order cycle could actually be lengthened without adverse reactions from customers. 21 In general, the longer the holding time the greater the probability that a volume shipment will be formed. 22 In an environment in which the receipt of an incoming order for a particular customer location and the size of the order are stochastic processes the actual length of the holding time may be quite variable and difficult to predict. Such factors as seasonality of demand and promotion programs which vary by time of year and geography further complicate the analysis.
It is also interesting to note that since a volume shipment will usually have a faster transit time than an unconsolidated LTL shipment it may be possible to introduce a consolidation system to a firm and maintain established order cycle times by letting the holding time offset the reduced transit time.\textsuperscript{23}

The length of the holding time allowed by the firm can also be seen as critical since a longer holding time can increase the probability that more of the middle group of clusters will accumulate volume shipments, thus reducing transportation costs.\textsuperscript{24} However, due to the stochastic nature of demand a higher level of variability may be introduced to the order cycle if the order is released when it attains the appropriate weight, since consolidation may be achieved at any time during the holding time.

Stop-offs

The addition of the stop-off privilege to the analysis may offer the firm an opportunity to add lower volume clusters to a consolidation program without jeopardizing customer service. The stop-off privilege allows the shipper to combine a number of less-than-volume shipments destined for points intermediate to the final stop into a volume shipment.\textsuperscript{25} The carrier will then stop at the intermediate point(s) to partially unload the shipment. The disadvantages of stop-offs are that the line-haul transportation charges to the stop-off points may be higher since they are based on the last stop and there is an additional charge for stopping in transit.\textsuperscript{26} There are also a number of constraints on the use of stop-offs. (1) the stop-off point must be intermediate to
the final destination and (2) the number of stop-offs is usually restricted to three and the final destination but this will vary depending on the carrier and the tariff. Stop-offs are also used by many firms to deliver relatively large orders (over 5,000 lbs.) to customers located near or even in the pool city. In these cases, all of the orders in the shipment gain from the volume through rate and the stopped-off portion avoids the redistribution charge.

Using stop-offs, the firm can realize many of the benefits of consolidation and yet release shipments which would only have achieved the necessary size individually through a longer than acceptable delay time.

From this discussion it can be seen that the order consolidation problem is a complex one which requires a great deal of effort by well trained and experienced individuals to analyze, implement and maintain it. It can also be seen that the effects of the number of breakbulk points, the maximum holding time allowed for orders and the use of stop-offs on the cost and service performance of the distribution system are highly interrelated. Furthermore, as will be shown in Chapter II of this thesis, the problem of order consolidation has been approached only on a limited basis by both academics and practitioners and as a result few principles and guidelines concerning order consolidation have been established through research. Also, a satisfactory methodology for analyzing, planning and operating an order consolidation strategy is not available in the public domain.
Purpose of the Study

It is the purpose of this research to develop a reliable, flexible and practical methodology for comprehensively analyzing an order consolidation system and demonstrate its use by investigating several major relationships within an order consolidation system. More specifically, the purpose or objectives of the study are:

1. to develop a computer based simulation model of a distribution system for a firm handling a given volume of nonseasonal, packaged consumer goods, nationally, from a single origin.

2. to utilize the validated simulation model to investigate the response of the distribution system's cost and service performance to changes in
   a) the number of consolidation zones or points
   b) the maximum holding time allowed
   c) the use of stop-off privilege
   d) the interrelationships of these three factors

System performance will be measured in three ways: (1) total system costs, (2) order cycle length, and (3) order cycle variability. Total system cost is important because it is the primary function of a consolidation system to lower the line-haul transportation costs more than other costs are raised. In addition, order cycle length and variability have been shown to be important criteria for evaluating customer service performance.

Research Questions and Hypotheses

The establishment of consolidation zones or service areas surrounding breakbulk points is central to any order consolidation system. These zones are usually established where there is a high volume of LTL freight. If all potential consolidation points are
ranked according to savings through consolidation, it is important to
know what happens to the system as lower ranking consolidation zones are
added. At what point, if at all, will the costs or service penalties
exceed the savings? Currently, there is very little in the literature
available as a guide in this decision. The specific question to be
answered in this research is:

1. How does increasing or decreasing the number of consoli-
dation zones or points affect total system costs, order
cycle length and order cycle variability?

The exact point at which consolidation points or zones will no longer
be added will, of course, vary from firm to firm depending primarily on
customer service requirements and the ability of the system to handle
the complexities involved in any consolidation strategy. This research
will derive the form of the relationship between a number of consolidation
zones and the distribution system's cost and service performance. This
relationship should be generalizable to a number of firms.

The specific hypotheses related to research question one which will
be tested in this thesis are stated in the null form as follows:

\[ H_0^1 \] Increasing the number of consolidation zones from zero
to 30 to 60 to 90 to 120 to 150 will have no effect on
total system cost

\[ H_0^2 \] Increasing the number of consolidation zones from zero
to 30 to 60 to 90 to 120 to 150 will have no effect on
average order cycle time

\[ H_0^3 \] Increasing the number of consolidation zones from zero
to 30 to 60 to 90 to 120 to 150 will have no effect on
variance of the order cycle

The problems of how long to hold orders to achieve a volume shipment
will also be addressed in this study. The literature provides two some-
what conflicting heuristics regarding the maximum holding time for orders.
Newbourne says that, in general, holding orders for longer than three days will not significantly improve the number of orders consolidated. However, Lai and LaLonde found that order consolidation did not improve noticeably after one day. It would seem logical that for high volume points a few holding days would be sufficient to achieve volume loads and that the maximum number of holding days would not even be a problem. However, low volume consolidation points may have somewhat erratic demand and holding periods of one or three or five days may make little difference but ten or fifteen days may have a considerable impact. Customer service requirements defined by order cycle length and consistency will influence the choice of holding times for the individual firms. The specific question under investigation is:

2. How does increasing or decreasing the maximum holding time for orders affect total system costs, order cycle length and order cycle variability?

The specific null hypotheses based on research question two to be tested are:

- **$H_{o4}$**: Increasing the maximum holding time for orders from "ship immediately" up to an unlimited maximum holding time will have no effect on total system cost

- **$H_{o5}$**: Increasing the maximum holding time for orders from "ship immediately" up to an unlimited maximum holding time will have no effect on the average order cycle

- **$H_{o6}$**: Increasing the maximum holding time for orders from "ship immediately" up to an unlimited maximum holding time will have no effect on the variance of the order cycle

Stop-offs allow the consolidator to combine less-than-volume shipments to different zones and still realize a portion of the transportation savings from consolidation. The relative value of the
stop-off provision has never been investigated in relation to order consolidation. This research will investigate the following questions related to the use of stop-offs.

3. How does the use of the stop-off privilege affect total system cost and order cycle length and variability?

The null hypotheses constructed to answer research question three are:

\( H_0^7 \) The use of the stop-off privilege has no effect on total system cost

\( H_0^8 \) The use of the stop-off privilege has no effect on the average order cycle length

\( H_0^9 \) The use of the stop-off privilege has no effect on the variance of the order cycle

The real value of the stop-off privilege will probably be seen as the number of consolidation zones increases and the maximum holding time decreases. As low volume zones are added, it may take longer to accumulate a volume shipment in the time allowed thus requiring stop-offs. Stop-offs may provide a valuable instrument for expanding the use of a consolidation strategy without jeopardizing customer service standards. Thus, the final research question can be stated as:

4. How do the number of zones, the maximum allowed holding time and the use of stop-offs interact to affect total system costs and order cycle length and variability?

Research question four requires an investigation of the three variables with one another in pairs and all together. The interaction effect refers to the response which cannot be predicted from the effects of the factors individually.
Research question four requires that twelve null hypotheses be tested. The first three hypotheses are designed to test the two factor interaction between increasing the number of zones and the maximum holding times.

\( H_{010} \) Increasing the the number of zones from zero to 150 in increments of 30 and increasing the maximum holding time in increments of one day from zero days up to a point where the effect is equal to an unlimited holding time produces no interaction effect on total system cost

\( H_{011} \) Increasing the number of zones from zero to 150 in increments of 30 and increasing the maximum holding time in increments of one day from zero days up to a point where the effect is equal to an unlimited holding time produces no interaction effect on the average order cycle

\( H_{012} \) Increasing the number of zones from zero to 150 in increments of 30 and increasing the maximum holding time in increments of one day from zero days up to a point where the effect is equal to an unlimited holding time produces no interaction effect on the variance of the order cycle

The next three hypotheses are designed to test for the interaction effects of increasing the number of zones and the use of the stop-off privilege.

\( H_{013} \) Increasing the number of consolidation points and zones from zero to 150 in increments of 30 and using the stop-off privilege results in no interaction effect on total system cost

\( H_{014} \) Increasing the number of consolidation points and zones from zero to 150 in increments of 30 and using the stop-off privilege results in no interaction effect on the average order cycle time

\( H_{015} \) Increasing the number of consolidation points and zones from zero to 150 in increments of 30 and using the stop-off privilege results in no interaction effect on the variance of the order cycle
Hypotheses Sixteen through Eighteen are designed to test for the two factor interaction effects of increasing the maximum holding time and the use of the stop-off privilege on the performance of the system.

\( H_{016} \) Increasing the maximum holding time in increments of one day from zero days up to a point where the effect is equal to an unlimited holding time and the use of stop-offs produces no interaction effect on the total system cost.

\( H_{017} \) Increasing the maximum holding time in increments of one day from zero days up to a point where the effect is equal to an unlimited holding time and the use of stop-offs produces no interaction effect on the average order cycle time.

\( H_{018} \) Increasing the maximum holding time in increments of one day from zero days up to a point where the effect is equal to an unlimited holding time and the use of stop-offs produces no interaction effect on the variance of the order cycle time.

The final null hypotheses are designed to test the three factor interaction effects on system performance of increasing the number of consolidation points and zones, increasing the maximum number of days holding time allowed and the use of the stop-off privilege.

\( H_{019} \) Increasing the number of consolidation zones from zero to 150 in increments of 30, increasing the maximum number of days holding time allowed from zero to a number of days at which system response is equal to the response of the system when an unlimited number of days are allowed and the use of stop-offs results in no interaction effect on total system costs.

\( H_{020} \) Increasing the number of consolidation zones from zero to 150 in increments of 30, increasing the maximum number of days holding time allowed from zero to a number of days at which system response is equal to the response of the system when an unlimited number of days are allowed and the use of stop-offs results in no interaction effect on the average order cycle time.
Increasing the number of consolidation zones from zero to 150 in increments of 30, increasing the maximum number of days holding time allowed from zero to a number of days at which system response is equal to the response of the system when an unlimited number of days are allowed and the use of stop-offs results in no interaction effect on the variance of the order cycle.

Scope of the Research

The scope of the study will be limited to a packaged goods firm with national distribution, nonseasonal demand and a predetermined amount of throughput. Furthermore, only outbound consolidation from one origin will be considered. There will be only one location from which shipments will originate. The distribution channel will be direct from that location to the customer by way of a pool distributor if consolidation is used. Otherwise the shipment will move directly to the customer. Product will not be stored and shipped from any other locations. The firm will be assumed to ship only one product. The geographic distribution of demand will be in direct proportion to the population of the U.S.

Research Methodology

The research methodology utilized in this thesis can best be described as experimentation with a computer based simulation model. It will be shown in Chapter III that a heuristic simulation model is the best alternative technique available since a manual or even a manual/computer assisted approach would be too cumbersome considering the data requirements and the stochastic nature of the system to be
modeled. Likewise, a mathematical programming model could not reflect the stochastic qualities of the system nor could it adequately integrate the time and cost relationships necessary for a meaningful representation of an order consolidation system. The methodology consists of four major steps: (1) formulation of the computer model, (2) validation of the computer model, (3) the experimental design and (4) the analysis of the simulated data.

Formulation of the model consists of a statement of the objectives of what, in general terms, the model must do to be useful in testing the hypothesis and answering the research questions. The next step in formulation of the model is to specify in detail the relationships and decision processes. This involves representation in mathematical terms where possible and flowcharting of the process. The final step in formulation is to choose the appropriate computer language, code and debug the program.

Validation of the model is conducted at several levels. First, great care is taken to insure that the relationships are specified properly in the formulation stage so that the model is conceptually valid. Once the model is coded and running on the computer the detailed mechanics of it are verified by testing small amounts of data for which the correct responses have been determined outside of the model. Finally, the model is run full scale and the responses checked for reasonableness.

The experimental design is a three factor, full factorial design. The three factors and their levels are (1) the number of consolidation zones from zero to 150 in increments of 30, (2) with and without stop-offs
and (3) the maximum holding time from "ship immediately" to a response equal to an unlimited maximum holding time in increments of one day. The number of observations per cell will be determined after trial runs designed to estimate the statistical characteristics of the responses. There are three sets of responses: (1) total costs, (2) average length of the order cycle and (3) variance of the order cycle.

The analysis of the simulated data consists of testing each of the twenty-one null hypotheses using the analysis of variance (ANOVA) technique. If the null hypotheses are rejected at the 0.95 level, the sample means will be ranked using a multiple comparison technique. It is the results of these rankings that will provide insight into the direction of the variances.

Limitations of the Research

The study is limited to an examination of order consolidation in a hypothetical firm which may or may not be directly comparable to any existing firm. Therefore, the results of this study can only be generalized to specific firms with great care, because critical differences may be present which would produce results at variance with those of this study. Several examples of how a firm's distribution system might be different from the hypothetical firm in the study are:

1. The firm may have more than one production location producing a different set of demands on the system in terms of order cycle times and costs. The geographic location of such origins in relation to each other and to the market could affect the relative feasibility of an order consolidation strategy.
2. The various products of a firm may not be suitable for coloading in transportation vehicles because of govern­ment regulations involving health and safety, and because the products may be damaged if coloaded. Product incompatibility can complicate the order consolidation process and perhaps render such a strategy ineffective.

3. The availability of carriers and shippers' agents to the individual firm might affect the desirability of a consolidation strategy. Order consolidation may not be possible for a particular firm without assistance. This assistance is assumed in the study to be available.

4. The characteristics of a firm's order flow in terms of the size of the orders, their numbers and temporal and geographic variations could influence order consolidation dramatically. An order flow characterized by a few large orders geographically dispersed with very erratic arrival times may experience results very different from the hypothetical firm in this study.

Many other examples are possible but they would only serve to further highlight the fact that the results of this study, while applicable to many firms, must be cautiously applied to any particular situation.

There are several limitations imposed on the study by the avail­ability of appropriate data.

1. Customer locations must be aggregated since it will be impractical to include every city and town in the U.S.

2. The maximum number of possible pool points is limited by the availability of freight rates from each pool point to each possible demand point. This limitation adds significance to the volume of shipments used in the study since a firm with a very large volume may choose to operate with more pool points than a firm with a relatively small volume.

3. Only class freight rates are used in the model. The inclusion of commodity rates would serve to increase the attractiveness of a consolidation system because they would widen the spread between volume and less-than-volume rates.
4. The only mode of transportation represented in the study is motor carrier.

Potential Contributions of the Study

The major contributions of this study can be described as managerial, methodological, social and environmental.

The managerial contributions of this study are based on the improved distribution efficiencies made possible to organizations through increased understanding of the relationships of major variables in the distribution system. For example, the sensitivity of costs and service to variations in the number of pool points for a given volume of demand will be more clearly understood as will the value of the stop-off privilege. Thus, a distribution manager will have a better perception of the relevant number of pool points a particular firm should consider employing and whether stop-offs could be an attractive method for reducing costs and improving service. Furthermore, the effect of the stop-off privilege on the relevant number of pool points to consider will also be better understood.

Furthermore, this study will serve to focus management attention on order consolidation as a viable alternative distribution strategy to LTL direct and field warehousing. It will stimulate questions concerning the appropriateness of these strategies for individual firms and markets and will spur analyses of them. Such analyses can be expected in many cases to lead to improved efficiencies.

In addition to stimulating analysis of small shipment distribution systems this study demonstrates the very effective analytical technique of computer based simulation as a method for analyzing such systems.
This method can be used as well to answer questions other than those addressed in this study. Thus, this study can be seen as spurring inquiry into small shipment distribution problems and as demonstrating a very effective methodology for conducting such analyses.

This study will therefore serve to improve the manager's ability to make sound and effective decisions concerning small shipment distribution which will result in more efficient and effective distribution systems.

The improved efficiencies made possible by this study will also lead to social and environmental benefits. Greater distribution productivity is based on a reduction in the consumption of resources used for distribution such as fuel, labor and vehicles which result in a reduction of the costs of goods to society and in a reduction of environmentally damaging air and noise.

Organization of the Research

Chapter I presents the statement of the problem, the research questions and hypotheses, the study's purpose and scope and a summary of the research methodology.

Chapter II presents the results of the literature review in three parts: (1) An introduction to order consolidation, (2) How order consolidation is conducted in practice and (3) the viewpoints of the carriers and society toward order consolidation. The first part surveys how order consolidation has been treated in the literature and provides a detailed description of order consolidation. The second part describes how it is accomplished in practice and focuses on how
the computer has been used for planning and operating order consolidation systems.

Chapter III presents the research design and methodology of the study. The chapter focuses on the determination of the functional relationships between the pertinent variables and discusses the development and validation of the computer based simulation model, the generation of data, the experimental design and the analysis of the results of the experiments.

Chapter IV contains the findings of the study. The results of the tests of the hypotheses and other findings are presented.

Chapter V contains a general summary of the study and presents the conclusions and implications drawn from the results of the research and other findings. The chapter concludes with recommendations for further research.
Chapter 1

Notes

1. See Appendix B for freight rate increases by three rate bureaus.


4. Ibid., p. 7.


8. See appendix C for definition.


10. Ibid.

11. Ibid.

12. Ibid.

13. See appendix C for definition.


17. Ibid.

18. Ibid., p. 45.


20. Ibid.
22. Newbourne, p. 46.
24. Ibid.
25. Flood, p. 256.
26. Ibid., p. 272.
27. Ibid.
28. Ibid.
29. Lalonde and Zinszer, p. 72.
30. Newbourne, p. 16.
32. See appendix C for definition.
II. A REVIEW OF THE LITERATURE

The objective of this chapter is to present in three sections a survey of the literature relevant to this study. The first presents an overview of how order consolidation has been treated in the literature, a description of order consolidation economics and patterns and a detailed presentation of the mechanics of order consolidation systems including legal constraints. The second section discusses how order consolidation systems have been planned and operated in practice with particular emphasis on the role of the computer in such efforts. The third section presents the viewpoints of transportation companies and society toward order consolidation. The overall purpose of this chapter is to present a comprehensive view of order consolidation which can be used as a basis for the design and implementation of a research methodology capable of providing answers to the hypotheses presented in Chapter I.

An Introduction to Order Consolidation
From the Shipper's Point of View

This section begins with a very general description of how order consolidation has been treated in the logistics, transportation, traffic management and distribution literature. Next, order consolidation is defined and four basic patterns of order consolidation are presented. The last three sections present detailed descriptions of (1) modifications
to the basic patterns of consolidation including stop-offs, (2) the effect of consolidation on common carrier freight rate determination and (3) the legal constraints of order consolidation.

An Overview of the Treatment of Order Consolidation in the Literature

Order consolidation is mentioned in business logistics and transportation and traffic management texts as well as in a number of trade journal articles. Almost all of these treat it in a very descriptive and usually incomplete fashion.

The transportation and traffic management literature recognizes order consolidation as a method to save substantial amounts of freight dollars while generally ignoring its effect on other areas of the logistics system, such as customer service and inventory management.¹ The traffic management literature discusses in detail the mechanics of freight consolidation such as stopping-in-transit to load and unload, mixed shipments and overflow rules.² These treatments are all very descriptive with little or no analysis of the effects of order consolidation on such things as order cycle length and variability, inventory levels, warehousing or order processing.

Prior to 1977 the business logistics literature merely presented a summarized version of the traffic management literature's treatment of order consolidation.³ Consolidation was not presented or discussed as an alternative distribution strategy to field warehousing or direct shipments. Since 1978 order consolidation has been presented and described by several authors as a viable small shipment strategy.⁴
These authors provide a surface treatment of order consolidation stressing its cost saving potential.

With the exception of one analytic study of order consolidation, the business logistics literature, like the traffic management literature is generally descriptive with regard to order consolidation. The business logistics literature is beginning to recognize order consolidation as a viable distribution strategy but it has not generally begun to offer analyses of it.

The transportation and distribution trade journals have described 1) the benefits of order consolidation, 2) the agents available to provide consolidation services, 3) several case studies of how order consolidation has been implemented and 4) order consolidation as a solution to the small shipments problem. In addition, a series of articles by Newbourne and Barret provides the most comprehensive look at order consolidation available. All of these articles tend to be very descriptive offering mostly "rules of thumb" unsubstantiated by empirical evidence or analysis.

Order consolidation has also appeared in the urban transportation literature. Consolidation terminals handling all small shipments into a metropolitan area have been proposed to reduce congestion, air pollution, noise pollution, fuel consumption and the price of products. At this time, however, the concept of an urban consolidation terminal has not been successfully implemented.

It can be concluded that in general order consolidation has been treated in a descriptive, often superficial and incomplete manner with little, if any, rigorous analysis applied to it. Furthermore, it has
only recently been recognized as a viable logistics strategy. The remainder of this chapter attempts to piece together a comprehensive picture of order consolidation from the literature.

Defining Order Consolidation

There are several definitions of order consolidation presented in the literature. Newbourne defines it as "the transforming of large numbers of (relatively) little shipments into small numbers of (relatively) large ones." Schuster defines it as "the combining of two or more shipments with the same origin-destination pair into a single larger shipment." Heskett takes the broader view that "consolidation involves practices which encourage the simultaneous storage, line-haul transportation, or delivery of two or more products or orders to achieve economies of scale." From these definitions there appears to be agreement that order consolidation involves the combination of two or more orders for at least a portion of their journey to a final destination. It is interesting to note that Newbourne refers to "freight consolidation," Schuster to "shipment consolidation" and Heskett to "combining orders." These three terms will be considered identical for the purposes of this thesis, however, it does seem that from the viewpoint of the shipper it is appropriate to think in terms of the joining together of orders to increase shipment size while from the carrier's viewpoint shipment and freight consolidation seem more natural terms.

Order consolidation does not necessarily result in a volume shipment. It may result in only a larger less-than-volume shipment.
Newbourne uses the term "pooling" to refer to an aggregation of orders which remains LTL or LCL in total. In pooling, orders are consolidated to form a larger but still less-than-volume shipment. Pooling can achieve many of the benefits of a volume shipment but to a lesser degree.

Order consolidation may be achieved for varying portions of the trip from origin to final destination. Aggregate tender refers to the consolidation of LTL orders for pickup by a single carrier and vehicle at one time. 16

"Simply put, large carriers offer discounts to shippers capable of tendering to them, at one place and at one time, substantial numbers and weight of LTL shipments.

"The discount is generally a flat amount per hundred pounds and is given when the carrier receives a stated volume of business, as 5,000-12,000 pound lots or 20 to 50 shipments under the conditions stated." 17

Aggregate tender therefore involves consolidation of orders at the shipper's dock until they reach the carrier's terminal where the individual orders are handled as LTL shipments if their destinations are different.

Pool car and pool truck operations are terms often used in the literature to refer to a method of distribution involving order consolidation. 18 In pool car and truck operations orders are consolidated into volume shipments for the line-haul movement. Either the shipper himself or his agent will perform the consolidation of orders at the origin or will break bulk at the end of the line haul movement and distribute the individual orders to their final destinations. 19
Pool operations should not be confused with pooling which was discussed earlier.

Hybriding is a term suggested by Vreeland to refer to "the use of some intermediate handling of freight, not directly associated with the normal door-to-door service of an intercity carrier subject to regulation." He explains that "hybriding" consists of three basic transport system practices which are (1) consolidation of freight into volume quantities at one point for shipment to one or two customers in distant destinations (2) shipping a volume quantity of orders to a market area where it is received by a shipper's agent who will unload, sort and distribute each order to the final customer and (3) the use of consolidating agents by smaller shippers who alone have insufficient orders to achieve the necessary volume.

Since these three systems are merely three variations of pool truck and car operations and because "hybriding" has not attained widespread usage in the literature it will not be used in this study.

Motivation for Employing An Order Consolidation Strategy

The primary motivation for employing an order consolidation strategy is economic. It is more efficient on a per unit basis to handle larger volumes than to handle small volumes of goods because the carrier expends very few additional resources handling the volume shipment up to the capacity of the vehicle than it does handling the smaller, less-than-volume shipment.
The common carrier rate structure reflects these economics in that per unit costs of transportation decrease as the size of the shipment increases. The graph shown in Figure 2-1 demonstrates the relationship of transportation costs per pound and the weight of the shipment. It can be seen that increasing the size of shipment decreases the per pound transportation charges dramatically for the first 5,000 pounds, after which the increases in shipment weight result in a more gradual decline in transportation charges per pound. The decrease in freight rates as shipment size increases is a result of the fact that pickup and delivery costs are largely fixed per stop regardless of the size of shipment. Thus, larger shipments provide more pounds for these costs to be spread over. One way to achieve this per unit reduction in transportation costs is to consolidate small orders into large shipments.

The differences in costs between large and small shipments are the result of several factors in the common carrier rate structure. Given a particular classification rating based on the product being shipped and the rate basis or distance factor the charges per hundredweight are stated for a number of progressively heavier shipment weights beginning with a minimum weight. Table 2-1 is taken from a page of a motor carrier freight tariff in which it can readily be seen that as shipment size increases the freight charges per hundredweight decrease. For example, class 100 shipments weighing less than 500 pounds will be charged $7.93/cwt (per hundredweight) declining to $7.44/cwt between 500 and 1,000 pounds, and $5.96/cwt for the next heaviest weight category. In addition, volume shipments usually qualify for a lower rating than
Figure 2-1. Transportation Cost per Pound by Shipment Weight

Source: Central States Motor Freight Bureau, Class Rate Guide no. 24 (Chicago, Ill., July 2, 1973) p. 12
### Table 2-1.

**An Example of Class Rates in Cents per 100 Pounds**

<table>
<thead>
<tr>
<th>Weight Group</th>
<th>Class 100</th>
<th>Class 70</th>
<th>Minimum Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 500</td>
<td>793</td>
<td>572</td>
<td>1145</td>
</tr>
<tr>
<td>500</td>
<td>744</td>
<td>530</td>
<td></td>
</tr>
<tr>
<td>1,000</td>
<td>596</td>
<td>429</td>
<td></td>
</tr>
<tr>
<td>2,000</td>
<td>525</td>
<td>381</td>
<td></td>
</tr>
<tr>
<td>5,000</td>
<td>445</td>
<td>312</td>
<td></td>
</tr>
<tr>
<td>TL</td>
<td>390</td>
<td>273</td>
<td></td>
</tr>
<tr>
<td>Incentive</td>
<td>349</td>
<td>244</td>
<td></td>
</tr>
</tbody>
</table>

less-than-volume shipments. Figure 2-2 is a page from the National Motor Freight Classification which shows lower classifications for truckload than for less-than-truckload shipments. For example the less-than-truckload (LTL) class for carpet is 100 while for a truckload (TL) quantity class 70 applies. The amount of the reduction in the rating will vary by product and can be substantial. For example, Newbourne reports that furniture in LTL quantities can move at classifications up to 300 while for TL shipments it can drop to as low as 50 or roughly one sixth the LTL rating.

The discussion thus far has centered on the structure of class rates. The shipper moving volume shipments repeatedly between two points can often negotiate lower rates further widening the spread between volume and less-than-volume rates and thereby increase the economic motivation for order consolidation.

The per hundredweight charges for a TL shipment will therefore be less than for an LTL shipment for several reasons: 1) a higher weight category will apply, 2) a lower classification rating will apply and possibly because 3) an even lower negotiated commodity or exception rate will apply.

The spread between TL and LTL rates has been widened in recent years through the differential application of percentage increases to TL and LTL freight rates. The graph in Figure 2-3 demonstrates the cumulative increases in TL and LTL rates from 1971 to 1977 in the Central Southern Rate Territory applying to glass bottles by comparing TL and LTL rates which were both $1.00/cwt in 1971 and have risen to $1.48 and $1.76 respectively in 1977 for a difference between TL and
<table>
<thead>
<tr>
<th>Item</th>
<th>ARTICLES</th>
<th>CLASS</th>
<th>CUBIC FT</th>
<th>POUNDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>70.10</td>
<td>Fine Nails, in machines ground tubes</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.15</td>
<td>Fine Straps, hemp, ground, in bags, tarred or baled</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.19</td>
<td>Fine Straps, hemp, in bags, TL, loose or in packages</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.20</td>
<td>Fine Straps, hemp, in bags, partially destarched</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.21</td>
<td>In bags or loose</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.22</td>
<td>Fine Ties or Oaken Lineages (Ties Lineages), TL, loose or in packages</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.23</td>
<td>Fine Ties or Oaken Lineages (Ties Lineages), TL, loose or in packages</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.24</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.25</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.26</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.27</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.28</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.29</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.30</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.31</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.32</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.33</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.34</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.35</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.36</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.37</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.38</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.39</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>70.40</td>
<td>Fine Ties, hemp, 70 lb.</td>
<td></td>
<td>12.5</td>
<td>25</td>
</tr>
</tbody>
</table>

**Figure 2-2. Page From National Motor Freight Classification.**
Figure 2-3. The Growing Spread Between TL and LTL Freight Charges on Glassware in the Central Southern Conference

Source: Based on tabulations of freight rate increases provided by Anchor Hocking Corp., Lancaster, Ohio
LTL rates on the same product moving between the same points has been significant since the LTL rates are substantially higher initially. ²⁷ Percentage increases tend to widen the spread between volume and less-than-volume rates even when the increases are equal. ²⁸

At the same time that the spread between TL and LTL freight rates has been growing the pressures on shippers to ship in smaller quantities were also intensifying. One of these pressures has been the proliferation of products in terms of distinctively new products and variations of old products. For example, the number of stock keeping units (SKU) in supermarkets more than doubled from 1950 to 1972 because of new styles, colors, flavors, brands, and package sizes and types while annual sales in constant dollars for each SKU fell from $238 to $145 during the 1950 to 1972 period. ²⁹ The result has been a greater and greater number of products being sold in smaller quantities in many industries. ³⁰

Technology has also played a part in reducing the size of shipments. ³¹ Such developments as the transistor and solid state circuitry have reduced the dimensions and weight of many products while increasing their value per pound. ³² The calculator is of course a prime example.

A related phenomenon has been the tendency for retailers and wholesalers to carry smaller and smaller inventories by requiring their suppliers to react quickly to smaller, more frequently placed orders. ³³ This phenomenon is intensified during recessionary periods as many retailers adopt "hand to mouth" buying practices. ³⁴
Still another factor has been the increasing decentralization of individuals and businesses away from the larger cities. The patterns thus established are characterized by a relatively low density of people and businesses. In total it becomes necessary to distribute a growing number of orders of decreasing size over a larger and larger area.

The net effect of these factors has been a force pushing toward smaller shipments while transportation costs have been encouraging larger shipments. Order consolidation offers the shipper caught between these opposing forces a strategy with which to reduce transportation costs and still satisfy customer demands for smaller orders.

Although the primary incentive for adopting a strategy of order consolidation is economic, there are several other advantages which are important. The first is that damage to shipments in transit can be reduced when orders are consolidated into volume shipments because volume shipments are physically handled fewer times than LTL shipments and thus exposed to possible damage or loss less frequently. LTL shipments will typically be handled once at the shipper's dock; twice at the carrier's origin terminal, twice at a breakbulk facility; twice at the destination terminal; and once at the customer's receiving dock totaling eight handlings. With a consolidated TL shipment there will be one handling at the shipper's dock and two handlings at breakbulk point and one handling at the customer's receiving dock for a total of four handlings. The number of handlings can be cut in half if the LTL orders are consolidated into volume shipments. An LTL shipment is thus more susceptible to damage and loss than a consolidated
load which moves undisturbed from origin to destination. It is also true that the more direct movement from origin to destination of the consolidated volume shipment will often result in a faster transit time for the consolidated shipment than for the LTL shipment. Total order cycle time may not be shorter since the orders may have to be held for a period of time in order to accumulate a volume shipment, thus offsetting the shorter transit time.

Moreover, as Taff points out in a discussion of an inbound consolidation program at Ford Motor Company,

"The savings are not merely monetary, for there has been a reduction in transit time of shipments which has permitted less material in transit and therefore less cash tied up in inventory. It has reduced the congestion at the shipping and receiving locations and has resulted in a reduction in telephone and telegraph cost, as well as labor cost involved in expediting shipments. In the Ford pool-car operations, there are cars which contain an average of 80 individual suppliers' shipments which go on a single bill of lading with but one car to trace and a single receiving spot required for unloading."

There is also evidence that in addition to a growing spread between TL and LTL rates there may also have been a general decline in service levels on less-than-volume freight. In fact Holloway goes so far as to say that "many shippers find it virtually impossible to obtain service on this category of freight." Order consolidation offers the shipper a way to counteract worsening service levels by increasing the size of shipments to weights which are attractive to carriers.
Patterns of Consolidation

The patterns of order consolidation vary from the simple to the complex. Newbourne discussed four patterns which order consolidation may take. The four patterns are illustrated in Figure 2-4.

Single pickup-single delivery is the most straightforward approach. It is used where the volume of orders is heavy between two points. Orders are accumulated at one point, consolidated into a shipment, tendered to the carrier as one shipment and unloaded at one final destination point. An example of this would be movements between two plants of the same company or individual orders destined for the same customer.

The single pickup-multiple delivery pattern occurs when orders are consolidated at one point such as a manufacturing plant for delivery to more than one location. The consolidated shipment may also be taken to a break-bulk point from where the individual shipments will be delivered to their final destinations.

"Here the shipper must establish a breakbulk point central to each destination area to which pooling is to be practiced. Consolidated lots are then shipped to these points, where they are disassembled into their individual components by personnel of the shipper or of the agent (warehouse, etc.) he has employed for that purpose, and reshipped in short haul truck service to their individual destinations."

In regard to pool car or pool truck shipments as described above, Flood points out that

"If properly planned, the sum total of the carload charge, warehouse unloading and checking fee, and local cartage at destination or LTL charge to another destination is generally considerably lower than the total separate LTL charges. In addition, less handling and often better service are obtained."
1. Single pickup - single delivery

2. Single pickup - multiple delivery

3. Multiple pickup - single delivery

4. Multiple pickup - multiple delivery


Figure 2-4. Patterns of Consolidation
Multiple pickup-single delivery can be referred to as inbound consolidation since it is most often controlled by the consignee. Shipments from a number of sources are consolidated at a point and shipped to a single destination. A manufacturer or retailer may purchase in LTL quantities from a number of vendors in an area and consolidate them into a TL shipment to a plant or store.  

"Where individual shipments have scattered origins but a common destination, the shipper employs short-haul trucking service—either on a private or for hire carriage basis—to gather them at a single point. He then groups them and reships them in consolidated lots, precisely as if they all originated at the consolidation point he has selected."

The multiple pickup-multiple delivery pattern is the most complex in that it wedds the single pickup-multiple delivery pattern to the multiple pickup-single delivery pattern. Orders from multiple sources are brought to a consolidation point and shipped in volume to a break bulk point for distribution.

Modifications to the Basic Consolidation Patterns

There are several possible modifications to the basic consolidation patterns discussed above which are beneficial under certain conditions.

Stop-offs

The primary modification in terms of this thesis is the stopping in transit to load or unload or simply the stop-off privilege. Figure 2-5 contains four diagrams of possible stop-off patterns. Points B and C can be thought of as break bulk points for consolidated loads or simply customers receiving relatively large orders. Points A and D are origins
1. Directly intermediate stop off to unload

2. Stop off to unload

3. Stop off to load

4. Stop offs to load and unload

Based on K.U. Flood, Traffic Management (Dubuque, Iowa: Wm. C. Brown Co.)

Figure 2-5. Possible Stop Off Patterns
of shipments destined for points C or B or points within C or B's distribution area. The line between A and B represents the shortest distance between the two furthest points, not necessarily the route traveled.

Flood points out that if handled properly the stop-off privilege can result in tremendous savings to the shipper. The following example highlights the freight cost savings potential from stop-offs:

"For example, if two 12,500 pound machines were shipped I.C.I. from Milwaukee, one to Atlanta, Georgia, and the other to Chattanooga, Tennessee, the freight charges in 1961 would have been $60 to Atlanta and $407.50 to Chattanooga, for a total of $867.50. Instead, these machines were both loaded in one 40-foot car, using one bill of lading, with instructions to stop the car at Chattanooga for partial unloading. By consolidating the two shipments, the carload freight charge was $487.50 plus a stop-over charge of $17 for a total of $504.50. The saving on this single shipment was $353."56

Stop-offs for both partial loading or unloading are possible as illustrated in Figure 6. Taff describes how the stop-off privilege can be used for both inbound and outbound consolidation:

"Under this privilege, a manufacturer can sell goods to two or more customers, load the goods in one car, and bill to the final destination, with instructions to stop at the intermediate point or points where part of the goods will be unloaded, after which the car will continue on its way with the balance of the load to the ultimate destination. The stopoff privilege to complete loading makes possible the purchase of goods at two or more origin points. The material which is purchased at the first point is loaded, and the car is billed to final destination to stop at one or more intermediate points for loading the additional merchandise."57
The shipper faces three major constraints in the use of stop-offs: (1) the number of stops allowed, (2) the charges for stopping off and (3) determining if a point is intermediate to the final destination.  

Flood points out that the number of stop-offs allowed varies by the carrier and the rate bureau. Some tariffs permit only one stop while in other tariffs three or more may be allowed excluding the initial pickup stop and final delivery stop. The number of stops to load, the number to unload and the total number of stops per trip may be individually specified. For example, Southern Territory Tariff S-236-D Item 3010 Rule 2 limits stopping in transit to load to not more than two stops per shipment, stopping to unload at not more than three stops and not more than an aggregate of three stops per shipment.

Stop-off charges will also vary by tariff and individual carrier. Some tariffs have a flat charge per stop such as $42.44 per stop for not more than three stops and $54.13 for each stop in excess of three stops. Others charge for stop-offs on the basis of weight handled at the stop-off point subject to a minimum charge. Occasionally a carrier will charge for stopping in transit on an hourly basis computed from time of arrival of the vehicle at the place of loading until completion of unloading at the final delivery site. Stop-off charges are in addition to the line-haul transportation charges and any other lawful charges applying to the shipment.

According to Flood route circuitry may be treated in one of three ways depending on the carrier:
1. The stop-off point must be intermediate on the normal operating route.

2. As long as the stop-off is profitable they will accept the shipment regardless of circuitry.

3. As long as the total distance of the trip with the stop-off does not exceed a certain percentage of the total distance from initial origin to final destination the shipment will be accepted.66

As an example, the Eastern Central Motor Carriers Association Rules Tariff specifies that

"If the total distance from initial origin to final destination exceeds 115% of the shortest mileage from initial origin to final destination, that distance in excess of 115% will be charged for at the rate of 109¢ per mile."67

The $1.09 per mile is in addition to the line-haul and stop-off charges.

The line-haul transportation charges are assessed on the basis of the greatest weight in the car or truck at any time between point of origin and final destination or the applicable minimum volume weight if that is higher.68

The applicable line-haul freight charges are determined by means of the "three way rule" which provides that the applicable rate is the one that produces the highest charge of the three following rates:

1. The rate from point of origin to final destination via the stop-off point or points.

2. The rate from point of origin to the stop-off point.

3. The rate from stop-off point to final destination.69

The exact statement of the "three way rule" may vary depending on the rate bureau as in the case of the Eastern Central Motor Carrier Association which specifies that for rate purposes the rate can be determined only from the initial origin or a stop to partially load--
not a stop to partially unload.\footnote{70}

Two other limitations which apply to the use of stop-offs and which may be of importance to this research are

1. All of the component parts of a shipment must be loaded and in transit before a stop for partial unloading can be made.\footnote{71}

2. All charges must be prepaid by the consignor and only one freight bill will be issued for the entire shipment.\footnote{72}

The second limitation will require a firm selling its products on a freight collect basis to alter its terms of sale.

Flood discusses a number of factors which are important to planning stop-off shipments.\footnote{73} He points out that it is important to be aware of the fact that distance is not always a good guide to the spread between the through rate to the top-off point and the through rate to destination due to the boundaries of rate territories.\footnote{74} For example,

"...if a shipper planned to originate a shipment at Milwaukee, stop-off at Louisville, Kentucky, final destination Bowling Green, Kentucky, it might be that a substantial spread in rates would result other than the uniform class rates, because these two points are in different rate territories. In such a case, the Louisville freight would be penalized because it would be charged the much higher rate to Bowling Green, although with respect to distance it would seem to be a logical stop-off point. This might still be preferable to making two separate shipments; but, on the other hand, the shipper might also have freight to other points farther away distance-wise but closer rate-wise. Combining these different shipments would bring about a finer breakdown for shipment planning, and, as a result, savings in freight charges. To illustrate, the Louisville freight could be tied in with Indianapolis freight and the Bowling Green freight with Nashville freight."ootnote{75}
Time in transit is another important factor in planning stop-off cars particularly since considerable delay may be experienced in switching and unloading at the stop-off point. Some delays would probably be experienced with a motor carrier stop-off also.

With regard to the firm's customary terms of sale Flood makes two pertinent observations. The first is that

"If the freight is not sold on a freight-prepaid basis and if separate customers are involved, a method of paying the freight charges must be worked out because the carrier will not collect a portion of the freight charges at the stop-off point. This can be done by shipping 'prepaid' and billing the customers their proportion of the freight charges at the carload rate plus their share of the stopping-in-transit charge."77

In addition, if the products are sold on a delivered basis

"...and the consignee does not gain anything from the consolidation of the shipment, he may object to this method of shipping, especially if he has to reblock the car or take team track delivery or if the shipments are being delayed at stop-off point."78

Split Pickups and Split Deliveries

Split pickups and split deliveries are a variation of stopping in transit to load or unload. The primary difference is that the stops occur within the commercial zones of the initial pickup or the final destination.79 Split pickups and deliveries are subject to the same charges and limitations as stop-offs.80

Transloading and the Marriage Rule

Transloading and the marriage rule are two variations of the stop-off privilege which are offered by rail carriers.81 Figure 2-6 presents a graphic representation of transloading.
Figure 2-6. Transloading

Flood describes the transloading privilege as follows:

"...the shipper of a carload shipment to be stopped in transit for partial unloading may request the carrier to unload at an intermediate point that portion of the shipment consigned to the stop-off point and reload it into a separate car (or cars) to be forwarded to its destination. Generally the tariff provision authorizing the transloading also specifies the point at which the transloading must take place. It also requires that the shipper notify a specified agent of the carrier that transloading is desired and provide information such as what freight is to be unloaded (sometimes a loading diagram is desirable), car number, date of shipment, and routing." 82

Transloading can result in much faster transit times than a stop-off car since no consignee's freight is held up at the stop-off point(s). 83

The transloading privilege is subject to all of the rules governing stopping in transit to unload including circuitry and the number of stops. 84

The "marriage rule" provides the same service as transloading but for stop-offs to load rather than unload.

"The 'marriage rule,' as it is commonly called, authorizes the loading of separate cars at the point of origin and at points for partial loading which are considered intermediate to destinations. Instead of stopping in transit a partially loaded car for additional loading, the railroad tenders another car to pick up the additional freight, the first car being allowed to move directly to destination. The billing nevertheless shows the 'marrying' of these two cars for purposes of obtaining the benefits of the stopping-in-transit privilege, in particular the lowest rate." 85

Transloading and the "marriage rule" are thus variations of the stop-off privilege which allow the railroads to provide a service which is more competitive with motor carriers in terms of transit times.
Freight Rates and Consolidation

Order consolidation can result in several variations in freight rate determination. These variations in freight rate rules are important to a discussion of order consolidation because they must be understood to arrive at the proper line-haul transportation costs.

Mixed Shipments

A mixed shipment consists of two or more articles for which the same or different rates or minimum rates apply. Such shipments complicate the rating process because there is more than one freight rate and minimum weight applicable to the shipment. This section will describe how the line-haul transportation charges for a mixed shipment are determined.

The first step is to determine the volume rate applicable to each article as if it was the only article in the shipment. That is, each article in the mixed shipment is charged according to the straight carload or truckload class or commodity rate applicable to it.

The next step is to determine the minimum weight applicable to the entire shipment and the rate at which the deficit weight, (the difference between the actual and the minimum weight) if any, will be charged. One of the following four methods will be specified depending on the rate bureau or the carrier:

1. The deficit weight is rated using the highest minimum weight of any of the articles in the shipment and the rate of the lowest rated article or a set rating regardless of what is actually in the shipment.
2. The deficit weight is rated using the highest minimum weight of any article in the shipment and the rate of the highest rated article. 

3. The deficit weight is rated using the rate of the article that constitutes the greatest weight of the shipment subject to the highest minimum. 

4. For shipments containing articles of equal weight, where no one article constitutes the greatest portion of the shipment, the deficit is rated using the lowest rate of the articles. 

There may also be tariff provisions for alternative methods of calculating charges, such as considering part of the shipment truckload and part LTL where the shipper is entitled to the alternative producing the lowest charge.

Mixed shipments may be subject to mixture provisions which prescribe the proportion of a shipment, by weight, which a specific article may not exceed. If the proportion is exceeded the excess will not be allowed to make up the truckload minimum weight and it will be charged for as a separate LTL shipment.

The problem of cost determination is obviously compounded when shipments have more than one commodity and each has its own mixture allowance provision to consider. Each rating alternative must be considered in order to arrive at the least expensive total charge.

**Mixed Shipment Commodity Rates**

Commodity rates on mixed shipments, where available, are simpler to determine than the mixed shipment rating procedure discussed above
because one rate and minimum weight applies to the entire shipment. Such rates are referred to interchangeably as "all-commodity rates," "all-freight rates," and "freight, all kinds." The rates are established on a graduated scale based on minimum weights and usually do not include pickup and delivery.

Flood reports that:

"There is no standard basis for constructing these all-freight rates; they vary considerably between different areas and between different points. The railroads have established these rates in the following manner:

72% of 1st Class Scale—minimum weight 12,000 lbs.
57% of 1st Class Scale—minimum weight 25,000 lbs.
44% of 1st Class Scale—minimum weight 40,000 lbs.

Other railroad tariffs publish all-freight rates based on a 30,000 pound minimum weight."

It must be pointed out that depending on the composition of the shipment it may be cheaper to rate it as a mixed shipment rather than to simply use an all-commodity rate. For example, a shipment which is composed of low rated articles may be charged more under a freight, all kinds rate than if each article is charged its own volume rate.

Overflow Shipments

It is not always required that the capacity of a vehicle dictate the upper limit to a consolidated shipment. Rule 24 of the Uniform Freight Classification specifies that "if in one shipment there is more freight than can be loaded in one railroad car, the overflow can be loaded in another car and go at the carload rate subject to these provisions:
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"a. The minimum carload weight must be 30,000 pounds or more.

b. Each car except the car carrying the excess must be loaded as heavily as loading conditions permit and must be charged at the actual weight, subject to the carload minimum weight. In other words, charges on the main car will be based on actual weight or carload minimum weight, whichever is the higher.

c. The car carrying the excess will be charged at the actual weight subject to the following minimum charge:

Closed car—10,000 pounds at carload rate applicable to the freight actually loaded in the part-lot car.

Open car—4,000 pounds at Class 100 rate.

Special cars, including damage free cars, permanent dunnage cars, and cars equipped with bars, racks, or other devices (not ordinary dunnage) used to secure the loading—15,000 pounds."99

Motor carriers do not have a general classification rule as the railroads have but instead individual tariffs may provide for overflow shipments.100

"As to class rates, the capacity load rules generally provide that, when a volume or truckload shipment, because of its quantity, exceeds the amount that can be loaded in or on a single trailer of not less than 26 feet in length, the minimum charges provided for in such rules apply to each fully loaded trailer required to transport the shipment, and the 'excess' which does not fully load a trailer will be charged for at the applicable volume or truckload rate at actual weight.

"As to motor carrier exception and commodity rates, there usually are no capacity load rules published for general application. But in many instances the rates are specifically made subject to capacity load rules, and the 'excess' will move either at the applicable volume or truckload rate at actual weight, or will be rated as a separate shipment at the l.t.l. rate, depending on the provisions shown in the particular capacity load rule."101
Interstate and Intrastate Shipments

In order to calculate the proper common carrier transportation charges it is necessary to determine whether a shipment crossed state lines and was therefore interstate or occurred within only one state and was therefore intrastate. 102 There are several situations involving order consolidation in which it is important to determine whether a shipment is interstate or intrastate.

The first case involves a situation where goods are shipped to a pool distributor from another state for delivery to customers of the shipper. 103 In this situation the entire movement of the shipment is considered to be interstate because

"1. At the time of shipment there is a specific order being filled for a specific quantity of a given commodity to be moved through to the customer's location in another state thus the intent of the shipper is to move the orders through to his customers.

2. There was not sufficient interruption in the journey at the agent's facility to break the continuity of the movement from shipper to customer. Therefore the movements from the shipper to the agent's facility and from the agent's facility to the customer cannot be viewed as separate and distinct movements but rather the entire movement is interstate. 104"

Thus, interstate freight rates apply on the entire movement.

The second case is where a private carrier transports goods from one state to another and then turns the shipment over to a for-hire carrier to deliver the shipment to the final destination within the second state. In this situation the common carrier would charge the intrastate rate because its service was rendered within one state. 105 Thus, a consolidated shipment carried by private carriage to a breakbulk
point in another state to be distributed by a common carrier within that state would be charged the intrastate rate.

The third case involves the comingling of interstate and intrastate shipments. If a consolidated shipment is composed of two orders, one destined for a customer within the originating state and the other destined outside of the state, the order delivered within the state moved in intrastate commerce and the other moved in interstate commerce.

Legal Constraints

The legal aspects of order consolidation center around the Interstate Commerce Commission (ICC) and Civil Aeronautics Board (CAB) because they regulate the common carriers—railroads, motor carriers, air carriers and surface and air freight forwarders—who may handle the consolidated traffic. Although they only have jurisdiction over the carriers and not the individual shippers performing their own consolidation, such regulations have an important, if indirect impact on the shipper.

The legal constraints on order consolidation are presented according to how they impact the common carrier and each of the three types of consolidation agents which may be employed to effect an order consolidation strategy.

The Common Carrier

In dealing with a common carrier, the ICC requires that one party other than the carrier exercise full operational and administrative
control over a consolidated shipment. Furthermore, the carrier cannot be made to apportion his bill among all of the consignors or consignees in the shipment. The freight bill must be presented to only one party who can then distribute the charges among the beneficiaries of the consolidated shipment. The carrier cannot perform consolidation for two or more shippers unless a formal buffer exists between the carrier and the shippers such as a consolidation agent. The buffer is presumably to prevent the carrier from practicing any form of discrimination or preferential treatment among shippers.

Consolidation Agents

If a firm chooses not to do all of its own consolidation there are organizations which can perform the entire consolidation service or a portion of it. These organizations may also be used in addition to the firm's own in-house consolidation effort. They may be particularly helpful with those shipments which do not fit the firm's own consolidation patterns.

Shipper's Associations or Cooperatives. Part IV of the interstate Commerce Act which regulates Freight Forwarders in Section 402(c)(1) excludes from regulation as freight forwarders

"...the operations of a shipper, or a group or association of shippers, in consolidating or distributing freight for themselves or for the members thereof, on a nonprofit basis, for the purpose of securing the benefits of carload, truckload, or other volume rates..."
Thus, where a formal agreement between two or more shippers exists for the purpose of combining shipments to secure lower transportation costs for members only will not be considered freight forwarders by the ICC. Any services performed in connection with non-members must be for the purpose of securing volume rates for members rather than profiting from the service to non-members itself.\textsuperscript{112} Newbourne points out that "...it is fully established that two shipper associations—unlike two individual shippers—may collaborate fully in joint consolidation activities...so long as the objective of each association is to obtain reduced transportation rates for its members through such coloading..."\textsuperscript{113}

It is less clear as to whether an association may legally mix freight with a non-member. Newbourne states that it would seem to be lawful as long as the association's objective is only to lower member's transportation charges but he says the ICC has limited this practice unless both the association and the non-member operate through an independent consolidator.\textsuperscript{114} The reason given for this restriction is that any profit potential will then go to the consolidator and not the association. Similarly, it is questionable if a freight forwarder and a shipper's association could comingle shipments because of the discriminatory factors which would be possible.\textsuperscript{115}

Taff states that consignors and consignees are usually divided into separate shippers' associations.\textsuperscript{116} A consignor shippers' association would be an outbound association and the consignee association would be inbound. He reports that the ICC "has frowned upon a consignor shipper's association sending freight bills to consignees for payment and crediting the savings to the consignor."\textsuperscript{117}
Taff makes some interesting observations as to how the ICC views the responsibilities of shippers' associations themselves and their members.

"...the Commission ruled that shipper associations do not qualify for exemption from economic regulation as freight forwarders if they are corporations as that term is commonly understood. In another case, the Commission stated that if a corporate charter of a shipper association relieves its members of liability or responsibility for corporate obligations, it is the type of organization not covered by the exemption. The Commission has further ruled that while an association is initially responsible for costs incurred in shipping goods in its own name, its individual shipper members are personally liable only for the charges relating to the transportation of the goods they beneficially own." 118

Apparently the ICC wishes to retain a liability distinction between shippers' associations and freight forwarders. Freight forwarders, like common carriers, assume full responsibility for shipments tendered to them while shipper associations do not.

Shippers' associations are non-profit and as such distribute all revenue in excess of costs back to their members. The costs to the shipper will include truckload transportation charges, handling charges, a drayage charge to the association's facilities and an administrative cost. 119 The individual shipper benefits from the increased volume of freight available to the association from all its members and thus the increased consolidation opportunities. 120

Newbourne points out that shipper associations are especially useful in consolidating shipments which cannot be combined with the firm's other shipments. 121
It is doubtful that a firm would use a shipper association to conduct all of its consolidation since

"These groups tend to specialize in particular geographic areas; the normal multi-destination shipper would thus be compelled to join a multiplicity of such organizations, even assuming he could find associations capable of handling the full range of his traffic. The resulting administrative problems would be formidable. Thus, the shipper's association is more often an adjunct to, rather than a substitute for, the company's own home grown consolidation program."122

Non-Regulated Shippers' Agents. Non-regulated shippers' agents are firms which are exempt from regulation by the ICC and are

"...in the business of consolidating or distributing property, sometimes called a pool car (or truck) operator whose responsibilities to shippers in connection with the consolidation or distribution of property are confined to the terminal area in which such operations are performed. At times a shipper may have neither personnel nor facilities necessary to consolidate or distribute his freight. A second party who offers and performs such services is a shipper's agent."123

Shippers' agents can be consolidators or distributors or both. Consolidators which are sometimes referred to as pool car or truck operations "are those where freight is held or gathered until there is enough volume to move it at lower carload rates."124 A distributor, sometimes called a pool car distributor "unloads, sorts and arranges for the distribution of numerous separate consignments received in volume truck or carload shipments."125

There are three organizational forms of shippers' agents according to Newbourne:
1. A warehouseman or distribution company offering breakbulk and consolidation in addition to its primary business of storage.

2. A subsidiary or affiliate of a line-haul carrier offering breakbulk and consolidation services.

3. A consolidator whose primary business is offering a for-hire consolidation service.

Shipper's agents, unlike freight forwarders, are exempt from regulation by the ICC. Part IV, Section 402(c)(2) of the Interstate Commerce Act states that the provisions of that part of the act which regulate freight forwarders do not apply:

"...to the operations of a warehouseman or other shipper's agent, in consolidating or distributing pool cars, whose services and responsibilities to shippers in connection with such operations are confined to the terminal area in which such operations are performed."

In distinguishing between freight forwarders and shippers' agents it must be kept in mind that freight forwarders offer and assume responsibility for the entire door to door movement of the shipment including terminal operations at both the origin and the destination and arrange for all transportation. The shippers' agent only performs the terminal operations at the origin end, and arranges for transportation to destination which may be the customer or another shippers' agent. "Once the goods have been turned over to a carrier, the agent's responsibility ends; it accepts no in-transit liability, and has nothing to do with terminal operations at the destination."

In addition, the shippers' agents are confined to the terminal area which refers to the city and its immediate environs.
"This does not mean the consolidator may not serve shippers whose plants lie beyond the terminal area, nor that it may not handle traffic destined to or emanating from points outside the terminal area. It does mean, however, that the consolidator may not exercise any routing, carriage or other operational control or have any active interest in those shipments as to their movements outside the terminal area. While the agent may (and many do) offer service in more than one such terminal area, this multiple service may therefore not be performed as to the same shipment; otherwise, the consolidator is construed to have invaded the field of freight forwarding, which it may not lawfully do."\(^1\)

The consolidator is normally compensated for his efforts on a fixed charge per hundredweight or per package subject to minimum charges.\(^2\) The consolidator, unlike the freight forwarder, takes no responsibility for loss and damage which might occur during the line-haul movement and therefore the shipper must file directly with the line-haul carrier to recover such losses.\(^3\) Newbourne points out that the shipper is perfectly free to make separate arrangements with more than one consolidating agent.\(^4\) One may be employed at the origin city and another at the destination city as long as the shipper retains operational control of the activities.\(^5\)

The essence of an outbound pool distribution system is to consolidate orders into a volume shipment, transport it to a consolidation/breakbulk agent who will distribute the individual orders to the appropriate consignees. This saves the shipper maintaining a facility and work force at that point to perform the same service.\(^6\)

**Freight Forwarders.**\(^7\) Under Part IV of the Interstate Commerce Act the ICC in 1942 was given broad regulatory authority over surface
freight forwarders engaged in interstate or foreign commerce.\textsuperscript{138}

Air freight forwarders are regulated by the Civil Aeronautics Board (CAB) and ocean freight forwarders are subject to limited regulation by the Federal Maritime Commission (FMC).\textsuperscript{139}

A freight forwarder is defined in the Interstate Commerce Act as follows:

"...any person other than a carrier subject to Parts I, II, or III of the Interstate Commerce Act which holds itself out to the general public as a common carrier to transport or provide transportation of property for compensation in interstate commerce and which (1) assembles and consolidates, or provides for assembling and consolidating, shipments of such property and performs, or provides for the performance of, break-bulk and distributing operations with respect to such consolidated shipments; (2) assumes responsibility for the transportation of such property from point of receipt to point of destination; and (3) utilizes in whole or in part the transportation services of carriers subject to Parts I, II, or III of the Interstate Commerce Act. The operating authority of such freight forwarders is a permit issued by the interstate Commerce Commission."\textsuperscript{140}

Freight forwarders have all the rights and obligations of common carriers but own no equipment.\textsuperscript{141}

Thus, a freight forwarder is a shipper's agent which offers door to door pickup and delivery service and assumes responsibility for the shipment from origin to destination. However, the primary benefit to be gained by the shipper from using a freight forwarder is faster service.\textsuperscript{142}

In general freight forwarder rates to shippers are the same as the LCL or LTL rates which the shipper would pay by rail or motor carrier.\textsuperscript{143}

The primary advantages of a freight forwarder over the other methods of consolidation are that the freight forwarder is responsible for the
shipment and thus liable for any loss or damage and the freight forwarder provides a total door to door service to shippers.

Therefore, freight forwarders provide the service advantages of consolidation and create few administrative problems for the shipper. However, to realize the economic advantages of consolidation the shipper must establish a consolidation program using either its own personnel and facilities, shippers' associations, shippers' agents or some combination of the three.

Environmental, Health and Safety Regulations

The coloading of different products in a vehicle is central to the concept of order consolidation and for many firms is of little legal significance. However, for others, such as chemical and food producers the coloading of certain products can be critical. Regulations and guidelines concerning the coloading of various materials are issued by such agencies as the Food and Drug Administration, The Environmental Protection Agency, The Occupational Health and Safety Administration and the U.S. Department of Transportation.

Several effects of hazardous materials regulations on order consolidation have been reported by a chemical company. For example, poisons are shipped separately to avoid any potential mix with food products. This requires the stripping of individual poisonous items from each order. The company also devised a computer program to total the weights of products in a shipment by hazard class to determine placarding requirements.
"If there is over 1,000 pounds of hazardous materials, there must be a set of four danger placards applied. If there is over 5,000 pounds of a single class of material loaded on any one vehicle at a single location, there must be additional placarding for that specific hazard class." [147]

Thus government regulations may complicate or even prohibit consolidation.

**Order Consolidation in Practice**

The purpose of this section is to provide insight as to how an order consolidation strategy is implemented in practice. A suggested procedure for the analysis and implementation of an order consolidation system is presented, followed by two cases of successful implementations of an order consolidation strategy. Finally, a section reviewing the use of the computer in order consolidation is presented.

**Establishing a Consolidation System**

The shipper in designing and operating a consolidation system is faced with a complex, constantly changing set of variables from which must be forged a viable distribution system. This section outlines a suggested four step procedure for analyzing and establishing an order consolidation system and mentions several of the major variables which might be considered at each step of the procedure. The procedure for establishing an order consolidation system is important to this thesis because building and experimenting with a computer based simulation model of a consolidation system requires in effect that a consolidation system be established.
Traffic Analysis. The first step involves a detailed analysis of traffic patterns. The analysis is conducted by choosing a relatively normal period of shipment activity, assembling shipment records for that period of time and sorting them to discover the firm's traffic patterns.

"The critical factors involved in a consolidation analysis are shipment frequency and weight; destination geography; and mode of transportation. In special cases certain additional factors may intrude; for example, need for speed of in-transit movement; shipment cube (or shape), or other unusual transportation characteristics."

Newbourne sees geography to be the key to consolidation.

"This may mean a multiplicity of shipments destined to a single customer...or to several different customers situated some distance apart but along a structured (or structurable) origin-to-ultimate-destination-route."

Three strategies of order consolidation are thus possible: (1) to a single customer, (2) to a number of customers in a geographic zone surrounding a break bulk point and (3) to an intermediate point via a stop-off.

Geographic groupings of demand (or supply) will begin to emerge: (1) those groups where consolidation appears to be very likely to be profitable, (2) those shipments which refuse to fit any of the patterns and (3) a middle group that appears suitable but does not quite fit.

Maximum Holding Time for Orders. The second step in the analysis is to begin to simplify the process by culling out that group of orders which clearly does not fit into a potential consolidation system.
Such shipments will be those not conforming to the geographic and temporal realities of the firm.\textsuperscript{155}

At this point the subject of a maximum holding time for shipments is brought into the analysis. Newbourne states that

"For reasons involving both statistics and common business practices, the chances for consolidation rise relatively slowly during the first day a shipment is delayed; improve considerably during the second and third days; and then, after about 72 hours, again tail off."\textsuperscript{156}

He goes on to conclude that "the optimum delay in order processing, from the traffic department's standpoint, is thus approximately three days..."\textsuperscript{157} The exact reasons for this phenomenon are not revealed by Newbourne. The possibility that the maximum holding time may vary by industry, by firm or by customer is not discussed. It is also interesting to note that in another section he states that "...the longer the delay, the greater will be the opportunities for consolidation."\textsuperscript{158} Apparently he means that the opportunities for consolidation increase over time up to a point after which they decline markedly. No empirical evidence is offered to support this contention.

Lai and LaLonde found in their study of order consolidation at the distribution center level that very little additional consolidation occurred after the first day because the orders were widely dispersed geographically and there were many orders requesting immediate shipment.\textsuperscript{159}

While the "optimum" holding time for orders is not clear there seems to be no question that order cycle time is an important variable in the customer service mix. LaLonde and Zinszer found that order
cycle time ranked second behind product availability in importance in evaluating a supplier's customer service performance. They also found in the same study that order cycle consistency was more important than order cycle length. These findings are consistent with Heskett's statement that order consolidation does not have to be achieved at the cost of reduced customer service. He provides an example in which a scheduled delivery system is used to provide an adequate accumulation period for order consolidation and at the same time a consistent order cycle time benefiting both customer and supplier. Furthermore, it has been found in a number of studies that order cycles are shorter than they need to be.

It is also possible, as Newbourne says, "...that reduced time in transit may partially or wholly compensate for the extra time the shipment spends being consolidated." It is clear that the effect of order consolidation on order cycle length and variability is important and must be considered carefully when establishing a consolidation system. Also, although the three day holding period may be optimal there is nothing offered to substantiate such a claim. It seems reasonable to assume that the optimal holding time will vary by a number of factors including the industry, the firm, the customer or even the time of year. It is also clear that the impact of consolidation on the order cycle may be relatively minor.

The timing constraint must be applied to the traffic analysis presumably to eliminate those points from the analysis which could not
accumulate sufficient volume within the maximum time allowed.\textsuperscript{166} It is not clear how to fully integrate the time factor into the analysis but it can be assumed that it would be quite difficult to accomplish, especially on a broad scale, using only static techniques.

Once the appropriate system of grouping shipments emerges the route structures can be defined.\textsuperscript{168} It is assumed that at this point the break bulk points have been chosen and the method of shipment to those points can now be defined. The actual procedure for arriving at this stage of the analysis is unfortunately vague.

\textbf{Detailed Economic Analysis.} The third step is a final examination of the results to weed out "those consolidation opportunities that have been defined whose 'net worth' proves to be so small as to render its value highly questionable."\textsuperscript{169} At this point the following should be known:

"1) where, and to approximately what extent, consolidation is possible; 2) the particular methods that will be employed to actualize these possibilities, including both company consolidated and shipper association consolidated freight; and 3) the approximate value of the economic benefits, both direct and indirect, that may be expected."\textsuperscript{170}

\textbf{Implementation.} The fourth step is that of implementation.\textsuperscript{171} Whether to use its own facilities or employ an agent or association to physically do the consolidation must be determined by the firm at this stage as well as how and where to handle the paperwork.\textsuperscript{172}

The process of establishing a consolidation system consists primarily of identifying all shipments by geographic destination and continually narrowing down the orders under consideration by deleting
those which do not fit into the system because of special customer requirements or geographic location. Geographic groupings are identified and the orders further refined by culling out those which cannot tolerate the maximum holding time criteria and which do not offer any economic advantages. The procedure is described in general terms leaving the particulars of the analysis and implementation of a consolidation system to the imagination and devices of the reader.

Two Cases of Consolidation Programs

Two examples of freight consolidation programs instituted by shippers are presented in order to gain insight into how such programs are initiated and operated in practice.

Honeywell. The commercial division of Honeywell produces and distributes internationally temperature controls, fire alarm systems and security detention systems for commercial buildings from plants in Arlington Heights, Illinois, Wabash, Indiana and Akron, Ohio and from distribution centers in Philadelphia and Toledo. Almost ninety-nine percent of the shipments from the plants move LTL to customers and the distribution centers.

In an effort to reduce the freight bill by reducing the number of small shipments a committee representing distribution, traffic and sales was formed. They agreed to experiment with shipping all orders directly to one sales office on a weekly basis from which they would be distributed to the construction site.

In this case, they defined the consolidation zone to be the sales territory for the sales office and the maximum holding time to be one
week. This experiment proved successful so it was expanded to all sales offices.

Consolidation was manual at the time of the report with the shipping foremen sorting the orders according to sales office but plans were being made to program the computer to perform this task.

**Department of Defense.** The Department of Defense's Military Traffic Management and Terminal Service (MTMTS) is a program which consolidates many small shipments originating in the Eastern United States and destined for West Coast bases and overseas locations.\(^{174}\)

The program began by checking the volumes and traffic flow of LTL shipments and then setting up a test consolidation at Philadelphia which lasted six months. Shipments weighing less than 10,000 pounds and originating within 300 miles were fed into an independent consolidator's facility. The article did not reveal any details concerning the traffic analysis, the decision to use a 300 mile radius or to use shipments under 10,000 pounds. The test resulted in significant cost savings as well as other improvements and was therefore expanded. Toledo was added with plans to add similar operations at Atlanta, Memphis, Chicago and New York.

The benefits realized were a $1.2 million reduction in the freight bill, reduced transit time from twenty days to ten days and a reduction in lost and stolen freight.

Although these two programs are of different patterns—Honeywell can be characterized as "one to many" and MTMTS is "many to many"—
several parallels can be drawn. Both programs began with some type of preliminary analysis to determine the volume of traffic flow between possible points and areas and the likelihood of cost savings. Although details of the conduct of the analyses are not revealed it seems reasonable to assume that they were largely a manual compilation of historical documents which resulted in the choice of the heaviest traffic routes. Similarly, in both cases the concept was tested on a limited basis before expanding the program. Newbourne mentions nothing of limited testing. When expansion did occur there was little consideration of alternative strategies or patterns reported. Expansion, as well as origination of the program, seems to have occurred on a trial and error basis. For example, in discussing expansion of the MTMTS program the following statement was made: "These new operations, like the original points, may be altered, cancelled or enlarged as experience shows best."175 Thus, limited analysis combined with trial and error on a small scale appears to be the method of establishing and expanding consolidation.

It is interesting to note that Honeywell instituted a maximum holding time for orders of seven days. Seven days conflicts with Newbourne's three day maximum discussed in the previous section. Maximum holding time did not appear to be a factor in the MTMTS program because of the very large volumes of shipments involved. As the program is expanded to lower volume points holding may become more important.
The choice of who should do the consolidation did not appear to be the subject of detailed analysis either. Honeywell used only its own employees and facilities while MTMTS used only independent consolidation agents.

Newbourne's third step which was to conduct a detailed cost analysis to insure that all shipments be included were truly of economic benefit was not followed very closely either. Rather, the consolidation zones were arbitrarily defined as the sales territory in Honeywell's case and as a 300 mile radius around the consolidation point in MTMTS case. Shipment size was also arbitrarily set by MTMTS at a maximum of 10,000 pounds.

The implementation stage as discussed earlier was conducted by setting up a trial operation involving the most promising point and then expanded to other points.

Thus, while Newbourne's steps can be identified in general in the cases of Honeywell and MTMTS the amount of detailed analysis suggested by Newbourne is clearly lacking. The unsophisticated level of analysis indicated in the cases is most likely due to the lack of data available for such an analysis and the unavailability of a suitable and practical methodology with which to conduct an analysis. The absence of specific guidelines by Newbourne to carry out what he says should be done suggests that appropriate methodologies are not currently available to many firms.

The next section presents a review of how the computer has been used for planning and operating order consolidation systems.
The Role of the Computer in Order Consolidation

The Honeywell and MMTS cases of order consolidation suggest that at least for some firms the computer does not play a large role in order consolidation. There are two studies available which provide some insight into the use of computers in order consolidation. Both studies consist of surveys of distribution executives in major U.S. firms. The first study which dealt with computer applications in distribution, by House and Jackson, found that approximately 40 percent of the firms responding indicated that the computer played some role in order consolidation at their firms. The second study by House which dealt with computer models in distribution found that the activity of order consolidation was modeled in a portion of the 73 models mentioned by respondents. Table 2-2 presents the responses by model type and segment of the logistics system. As can be seen in Table II, order consolidation is represented to some extent in only the facility location, transportation and total system models with the highest representation in the warehouse to customer segment.

While these studies provide some understanding of the use of the computer in order consolidation they have two serious shortcomings. The first deficiency is that it is not clear to what extent the findings can be generalized to all firms in the United States. For the survey by House this is particularly important since a firm which had no computer based models might have been reluctant to respond to the questionnaire at all. The second and more serious problem is that the
Table 2-2.
Percent of Models Representing Order Consolidation

<table>
<thead>
<tr>
<th>Type of Model</th>
<th>Inbound Raw Material</th>
<th>Within Plant</th>
<th>Production</th>
<th>Warehouse Plant</th>
<th>Customer</th>
<th>Beyond Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility Location</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>6.7</td>
<td>13.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Inventory Control</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Transportation</td>
<td>12.5</td>
<td>6.3</td>
<td>0.0</td>
<td>18.8</td>
<td>25.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Production</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total System</td>
<td>5.6</td>
<td>5.6</td>
<td>5.6</td>
<td>22.2</td>
<td>38.9</td>
<td>0.0</td>
</tr>
</tbody>
</table>

extent or the nature of the application is not revealed in either survey. For example, in the study by House and Jackson it is not known if the order consolidation effort is entirely conducted via computer or only assisted by the computer. In the survey by House it is impossible to know the level of detail to which order consolidation is represented in the model. For example, the model by Geoffrion which is discussed later in this chapter recognizes the probability of order consolidation to a customer zone by reducing the transportation charge to that zone prior to running the model. Would a respondent to House's survey indicate that the order consolidation activity was represented in such a model? The next two sections describe how order consolidation has been modeled in practice.

Order Consolidation in Distribution Models

A detailed review of two distribution models reported in the literature provides some insight into how order consolidation has been modeled. The two models are examples of distribution models in general representing a mathematical programming approach and a Monte Carlo/Simulation approach.

Geoffrion's model using Benders Decomposition Method. The purpose of this model is to optimally locate intermediate distribution facilities between plants and customers. The firm modeled is a large food processor with seventeen commodity classes, fourteen plants, forty-five possible distribution center sites and 121 customer zones. Production capacity and demand are assumed to be known and all demand is
satisfied by shipping through regional distribution centers (DC) although direct plant to customer shipments can be made. Each customer zone is served by only one distribution center. There are lower and upper bounds on the total annual throughput of each DC. The model chooses the optimal set of DC's from among those given. Transportation costs are assumed linear and DC costs are expressed as a fixed charge plus a linear variable charge.

The problem is to determine the size and site of each DC, the zones to be served by each DC and the pattern of transportation flows for all commodities. The objective is to fulfill all demand at the minimum total cost.

The problem is formulated as a single period mixed integer linear program and a solution technique based on Benders Decomposition is developed. This technique has the advantage of being able to decouple the multicommodity capacitated multi-echelon transportation portion of the problem into a classical transportation problem for each commodity. This computational technique was found to converge very quickly to a solution within one or two tenths of a percent of the true optimum.

The model can be classified as static in that it models only one period of time. It is also deterministic. Stochastic processes such as transit time and geographic demand are represented by average values.

For purposes of evaluating an order consolidation strategy this model has serious limitations. Much more detail is necessary to portray the relationship of cost and time in a consolidation system. To properly consider order consolidation the model must be capable of handling
individual orders rather than aggregating all orders by zones for one period of time. The individual order is the basis for analysis in order consolidation. The model must also be capable of determining very accurately the freight charges for individual orders and shipments to individual geographic points rather than the relatively large zones used by Geoffrion. Since the economic motivation for order consolidation is the spread between volume and less than volume freight rates, average freight costs to wide areas are inadequate. The model allows for some economies of scale in transportation costs from the plant to the DC by using lower freight rates as the volume moving between the plant and the DC increases assuming the ability to negotiate lower freight rates based on volume and heavier shipments.

Shipment consolidation and stop-offs are incorporated into the model by estimating their effect on the average freight rate from the DC to the customer zone and adjusting the rate accordingly. Thus order consolidation is an input to the model rather than a measurable outcome. Its effects in terms of cost and time are assumed to be known. The analysis of order consolidation must therefore be conducted outside of the model.

The deterministic nature of the model is also a problem for order consolidation. Demand in terms of order size, origin, products and arrival time as well as transit time are stochastic processes and their variability is crucial to the performance of an order consolidation system. Averages are not adequate especially when the effects of several stochastic processes are cumulative as they are in order consolidation.
An order consolidation model must be dynamic rather than static as Geoffrion's is. In order consolidation yesterday's events have a considerable effect on today's decisions and activities. For example, the orders held from yesterday must be known today in order to properly evaluate the consolidation opportunities for both days' orders.

In conclusion, the integer program using Benders Decomposition technique is unsuitable for investigating the cost versus service tradeoffs of order consolidation for a number of reasons. Primarily, its static and deterministic nature precludes a realistic portrayal of a highly stochastic and dynamic process.

Long-range Environmental Planning Simulator (LREPS) is a dynamic simulation model developed to assist management in physical distribution system design. It can model a national packaged goods distribution system with up to five levels and fifty individual products. LREPS is a very detailed and complex order by order simulation. It is stochastic and dynamic and does not optimize.

LREPS can consolidate outbound orders. Outbound orders are accumulated to individual customers and geographic zones over a predetermined period of time. The consolidated shipments are released when a volume quantity is accumulated or when the holding time runs out. Freight rates are calculated for the movement to the pool distributor but an average freight cost beyond the pool distributor is calculated.

There are several limitations to using LREPS to investigate order consolidation. One is the lack of precision in calculating the beyond
freight rates. These are necessary to properly evaluate the cost trade-offs of order consolidation. Secondly, LREPS has no provisions for the stop-off privilege which is an important part of many order consolidation programs. Finally, LREPS is too large and complex to be run for minor studies. Many of the features of LREPS, particularly those dealing with distribution centers, are not necessary to answer the research questions.

Reports of other distribution modeling efforts do not appear to treat order consolidation any more directly than do LREPS or Geoffrion.181

Order Consolidation Models

This section reviews a simple computer based model suggested for use in evaluating order consolidation strategies and two analytic studies which utilized computer based simulation models.

A time sharing consolidation program. Newbourne presents a simple prepackaged program to be used on a time-sharing network to roughly calculate cost comparisons of various consolidation strategies.182

The user builds files containing the volume of product shipped to each destination, the volume rate to that destination, the LTL rates for each weight category directly to the customer, the volume rate to the breakbulk point, any charges at the breakbulk point, the beyond rates for each weight category and the percentage of freight for each destination in each weight category. The user then specifies the percent of freight to be shipped direct via TL and LTL and through the warehouse. The computer then calculates the costs in total and broken
down by route for each destination and for all destinations. The user
tests various strategies by changing the percent of freight routed by
each method.

This program is of limited use for the purposes of this research
since it lacks a time dimension and aggregates orders by destination.
It also does not represent stop-offs.

SIMLOAD

SIMLOAD. SIMLOAD is a constrained simulation model developed for
the U.S. Army to evaluate policies governing the supply of overseas
operations from continental U.S. Supply points. The problem is to
reduce transportation costs and average response time by:

1. Minimizing the number of consignees in each shipping
   container.

2. Maximizing the amount of cargo in each container.

3. Minimizing the time cargo is held at the origin for
   consolidation and loading.

In general the low volume of cargo for many customers requires that
more than one consignee be loaded in one container.

The purpose of the model is to investigate container loading policies
and the clustering of consignees into zones. Consignees located in one
zone can be supplied in the same container. Container loading policies
consist of the holding times and the number of different consignees
loaded per container and the effect of alternative cluster arrangements.

The model is a constrained simulation model that evaluates
alternative loading policies and cluster arrangements. The model
correlates the variables, priority, consignee, hold time and cluster groupings to optimize loading factors using historical shipment data. The model can handle up to ten consignees simultaneously and any combination of one through to ten hold times.

The input data includes the

1. Maximum number of consignees per van
2. Maximum hold time for vans
3. Historical shipment data

The model accumulates daily receipts for each zone and then attempts to ship to one consignee. If the capacity is not filled within the allowable hold time, other consignees in the zone are used to fill out the load if they are available. Material may be split between containers.

Model output is presented in 10 by 10 matrices with the hold time in days on one axis and the number of consignees on the other.

The output matrices are:

1. The total number of pallets and vans loaded
2. Number of vans which are not economical
   (50 percent loaded)
3. Average number of days per pallets and vans
4. Average number of consignees per pallets and vans
5. Average cube per pallet and van
6. Number of pallets and vans that were shipped direct to one consignee
By varying the allowable hold time and the assignment of consignees to various zones, loading policies can be evaluated on several dimensions.

While SIMLOAD does perform consolidation it has a number of shortcomings in terms of this thesis. First, the very important cost factors are missing. The determination of transportation and inventory carrying costs are critical to this research. Secondly, stop-offs are not represented in the model. Time factors, such as transit times and the variability of the order cycle are not included in the model.

Lai and LaLonde study. The Lai and LaLonde study is the only study which has specifically investigated freight consolidation using a computer based simulation model. The model, programmed in GASP IV, consolidates orders placed on a public warehouse and destined for the surrounding area. Order consolidation was achieved by matching the zip codes of each order and determining if it would be cheaper to consolidate the order or to ship it direct. If the consolidated line-haul freight rate plus either a cross-docking charge plus redelivery or a stop-off charge was less than the direct LTL charge the orders would be consolidated.

Consolidated orders were shipped if their weight exceeded a predetermined minimum weight or if their age exceeded a specified maximum. If the maturity date had not been reached, the orders would be held for possible consolidation with the next day's orders. If one order had reached maturity, the entire consolidated shipment would be released for shipment.
To save computer core all freight rates were calculated from either of two tariffs for one of two freight classes specified on the order. A single minimum charge was assumed.

The experiments conducted on the model consisted of varying the order weights, the number of holding days and the freight rates. It was found that savings dropped as the weights of the orders were increased by 500 percent and increased as the weights of the orders decreased by 75 percent and 50 percent. The order weights which the analysis started with played a critical role in the results.

The amount of savings was very insensitive to the maximum holding days. After the first day very few additional consolidations were made because a significant percentage of the orders were a "must ship" status and the geographic zones were dispersed. This is somewhat at variance with Newbourne's contention that most consolidations occur on the second and third days with very little consolidation thereafter.

Increasing the rate structure first 5 percent and then 10 percent produced increased savings but not always an increased percentage of savings.

Three major conclusions were drawn from the study. (1) The model presented demonstrated that it is possible to develop a model of freight consolidation to analyze various operating rules and strategies. (2) The potential benefits of consolidation to the firm depend upon the mix of shipment sizes, the structure of transportation rates and the holding time acceptable to the shipper. (3) The primary payoff from consolidation can only be realized if the firm is organized to make
it happen rather than merely allowing it to happen. It is also suggested that the public warehouseman should seek out accounts according to shipment locations and order characteristics which increase his chances of freight consolidation.

For the purpose of this thesis the Lai and LaLonde study is significant for several reasons. First, it demonstrates that it is possible to use a computer based simulation model to investigate order consolidation strategies. The model described in the study is a good approximation of a consolidation system, however, there are several areas where changes may be appropriate especially for firms distributing on a national basis. The territorial scope of the model should be enlarged. This would also require the definition of larger zones because as the line-haul distance from the origin increases the economical distance for redelivery will exceed one 5 digit zip code. Also, the addition of several echelons and multiple origins may be important.

In addition, a more accurate or complete method for determining freight costs may improve the accuracy of the model. This would be particularly important if the geographic and product scope of the study were expanded. A flat per hundredweight redelivery charge would prove too unrealistic on a national scale.

Lai and LaLonde have also raised doubts as to the validity of the three day maximum holding time heuristic put forth by Newbourne. The investigation of this heuristic is one of the primary purposes of this thesis.
Lai and LaLonde, by including the stop-off provision in their model also raise the question of its importance in consolidation. This too is one of the primary purposes of this thesis.

In this section it was shown that at least for some firms the computer does not play a major role in either the operation or planning of order consolidation systems in spite of the magnitude and complexity of the problem. Furthermore, where the computer has reportedly been used in relation to order consolidation the scope and detail of the applications are not known.

A review of several distribution models revealed several points of interest. First, order consolidation as discussed in this thesis has only been modeled once and that distribution models in general either ignore it, assume its effects on transportation costs to be known or treat it incompletely. Secondly, it could be seen that the ability to model an order consolidation system with its dynamic and stochastic nature is severely limited in a mathematical programming approach. The models with the most complete and realistic representation of order consolidation are the Monte Carlo/Simulation variety of models.

The Viewpoints of the Carrier and Society

There are two perspectives of order consolidation other than the shipper's which are important to this thesis. These are the viewpoints of the carrier and of society. Although order consolidation must be conducted unilaterally by the individual shipper both society and the carrier can help in this effort by providing incentives to shippers
to institute order consolidation programs. The most powerful of these incentives is a freight rate system which accurately reflects the costs of providing the service.

The Viewpoint of the Carrier

From the viewpoint of the carrier, order consolidation by shippers is a partial solution to the small shipment problem because it decreases the number of small shipments they must handle. The small shipment problem is illustrated in Table 2-3. From this table it can be seen that motor carriers in general experience losses on shipments weighing less than 500 pounds and earn relatively large profits on shipments weighing between 1,000 and 10,000 pounds. The magnitude of the problem is highlighted by the fact that approximately 75 percent of all shipments weigh less than 1,000 pounds. Furthermore, the number of small shipments and thus the problem has been growing in recent years.

Schuster summarizes the problem as follows:

"The present motor carrier LTL shipment rate structure causes shippers who use transportation strategies which cause average shipment weight to be large to subsidize shippers with small average shipment weights, certain classes of commodities to subsidize other classes of commodities, and the transportation rates paid by certain communities to subsidize the transportation services received by other communities."  

From the shipper's point of view the small shipment problem is composed of poor service coupled with high rates. The carrier characterizes the problem as being caused by shipper's tendering small
### TABLE 2-3
Operating Ratios\(^a\) by Shipment Weight, 1974

<table>
<thead>
<tr>
<th>Shipment Weight Category</th>
<th>Operating Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LTL Shipments</strong></td>
<td></td>
</tr>
<tr>
<td>Minimum Charge</td>
<td>134.4%</td>
</tr>
<tr>
<td>Less than 500 Pounds (other than Minimum Charge)</td>
<td>114.8</td>
</tr>
<tr>
<td>500-999 Pounds</td>
<td>95.4</td>
</tr>
<tr>
<td>Over 1000 Pounds</td>
<td>82.5</td>
</tr>
<tr>
<td>Overall LTL Operating Ratio (other than Minimum Charge)</td>
<td>91.0</td>
</tr>
<tr>
<td><strong>TL Shipments</strong></td>
<td>91.7</td>
</tr>
<tr>
<td><strong>Total Traffic</strong></td>
<td>94.6</td>
</tr>
</tbody>
</table>


\(^a\)The operating ratio is the operating expenses incurred in providing transportation services divided by the revenues received for the provision of the transportation service.
shipments requiring special services whose costs to handle are substantially higher than the revenue earned.  

The solutions to the small shipments problem are generally recognized to be the establishment of a rate structure based on costs and containing incentives for shippers to adopt strategies such as order consolidation which would serve to reduce the total costs of transportation.

Motor carrier LTL costs are essential to an understanding of the effects of order consolidation on the carrier. The costs involved in small shipment movements can be assigned to four cost centers: pickup and delivery, platform handling, billing and collection and line-haul movement. The first three are considered terminal costs. These three have risen more rapidly over time than the line-haul costs because of increased urbanization and congestion in U.S. cities and because the productivity of terminal operations, which are very labor intensive, has not kept up with increasing labor costs.

Schuster's study of motor carrier LTL services describes the relationship of shipment size to motor carrier costs and time. He found that pickup and delivery of shipments weighing less than 2,000 pounds took a significantly greater amount of time per hundredweight than those weighing more than 2,000 pounds and that pickup and delivery times increase with city size. He also found that pickup stops require less time per hundredweight than delivery stops and that stops at carrier terminals for interlining shipments require longer times than for other pickup or delivery stops regardless of the size of the city.
Translating these times into costs he found that stop costs per hundredweight decline rapidly up to shipment weights of 6,000 pounds with the rate of decrease declining markedly after 6,000 pounds. 197

For platform handling cost it was found that the mean cost per hundredweight declined rapidly until a shipment size of 5,000 pounds was reached at which point the rate of decrease slowed markedly. 198 Platform handling costs, therefore, behaved similarly to the pickup and delivery costs.

LTL billing and collection costs per hundredweight also declined with increased shipment size. The rate of decrease slowed between 5,000 and 6,000 pounds as it did for the pickup and delivery and platform handling costs. 199

It is intuitively obvious that all three of these cost categories have a threshold cost associated with them which must be incurred regardless of shipment size and which does not vary greatly as shipment size increases. For example, the costs of billing shipments of a certain product will be identical regardless of the weight of an individual shipment. Thus, combining two orders into one shipment will reduce the costs to the carrier because he will only incur those threshold costs one time.

Line-haul costs behave somewhat differently than pickup and delivery, platform handling and billing and collection costs. Line-haul costs per hundredweight were found to decline as trip mileage increased primarily because the average load factor tended to increase as trip mileage increased. 200 Holding trip mileage constant, however, the average
line-haul cost per hundredweight was found to remain constant regardless of shipment size. Line-haul costs are, therefore, insensitive to order consolidation whereas pickup and delivery, platform handling and billing and collection costs per hundredweight are very sensitive to order consolidation especially for shipment sizes under 6,000 pounds.

When Schuster combined all four of these cost elements, he found that total LTL shipment costs for the average length of haul declined from $10,229 per hundredweight for the 0 - 149 pound weight bracket to $1,203 per hundredweight for the 5,000 to 5,999 pound weight bracket. Thus, the variable costs per unit of weight decline as shipment weight increases.

It should be noted that order consolidation offers the carrier a greater cost reduction potential than multiple shipment tenders because there are no economies gained in the line-haul movement with multiple shipment tenders. When the multiple tender lands at the originating terminal, it is just so many LTL shipments from that point forward unless the shipments go to the same destination.

Schuster, in another study, demonstrated through a number of examples that "...motor carriers can realize large cost savings if shippers adopt a shipment consolidation strategy. The cost savings realized by the motor carrier should be shared with the shipper in order to induce shippers to adopt a shipment consolidation strategy. The most significant percentage cost savings can be realized by motor carriers when shippers consolidate shipments in the lowest LTL shipment weight brackets into larger LTL shipments."
"The cost evidence showed that short-haul, low-cost carriers can experience the greatest percentage cost savings and that long-haul, high-cost carriers can experience the greatest absolute cost savings. System-wide costs are inappropriate to use in determining the cost savings which would be realized from specific shippers adopting a shipment consolidation strategy. Therefore, cost savings should be computed on a traffic lane basis and the revised LTL shipment rate structure, which is needed to induce shippers to adopt a shipment consolidation strategy, should feature point-to-point LTL shipment rates."\textsuperscript{205}

There is also evidence that the carrier's payments of loss and damage claims might be reduced if shippers more widely practice order consolidation. The amount of money paid out in freight claims by carriers has been rising both as an absolute amount and as a proportion of total revenues in recent years.\textsuperscript{206} There is also evidence that the greater part of the claims fall into the LTL category.\textsuperscript{207} Small shipments are more susceptible to pilferage and damage than volume shipments and thus order consolidation can help to reduce such costs to the carrier.\textsuperscript{208}

There are therefore strong indications that order consolidation can help to reduce carrier costs by reducing the number of small shipments which must be handled by the carrier. Specifically, pickup and delivery, platform handling, billing and collection costs and loss and damage can be reduced by a decrease in the number of small shipments the carrier must handle. It is also evident that a restructuring of the freight rate system to accurately reflect carrier costs would provide a stronger incentive for shippers to consolidate small shipments.
The Viewpoint of Society

Order consolidation's greatest potential impact on society is in the movement of freight within urban areas. Intercity freight normally moves in volume quantities between carriers' terminals which are located in or near urban areas. Carriers follow a multiple pickup-multiple delivery pattern. They pick up and then consolidate at their terminal LTL shipments from many customers within a geographic area for the line-haul movement to terminals in other cities from which the shipments are broken up and delivered to their final destinations. Since orders are generally consolidated for the intercity line-haul movement by the carrier, order consolidation by shippers offers the greatest potential for the pickup and delivery portion of the movement by reducing the number of pickups and deliveries.

This section will show that urban freight distribution has a significant impact on the urban environment, that it is a major contributor to congestion and pollution, that it is grossly inefficient, that it increases the costs of distributing the products of society and that order consolidation by shippers offers at least a partial solution to the problem.

Even a minor reduction in pickup and delivery trips could have a significant impact on society due to the magnitude of intracity freight transportation because on a national scale local trucking is estimated to account for seventy percent of all truck trips. In addition, the expenditures for intracity trucking have grown at a faster pace than those for intercity trucking. Local trucking expenditures
increased $20.3 billion between 1960 and 1970 to $35.5 billion while intercity trucking only rose $16.5 billion to $34.4 billion.\textsuperscript{210}

The impact of a reduction in intercity trucking would be particularly great because of the spatial and temporal concentration of trips in the Central Business District (CBD) of major cities. It is estimated that thirty-seven percent of all local trucking either originates or terminates in the CBD.\textsuperscript{211} Furthermore, local trucking usually occurs during the daytime business hours.\textsuperscript{212}

With regard to shipment size and vehicle capacity utilization, McDermott observed in his survey of general freight moving in the Columbus CBD that 60 percent of the shipments destined for or originating from the CBD were less than 200 pounds and that over 90 percent were less than 1,000 pounds.\textsuperscript{213} He also found that the average vehicle capacity utilization was about 32 percent.\textsuperscript{214}

Cadotte points out that the effect of intercity trucking on the level of congestion can also be significant since trucks account for upwards of 20 percent of vehicle trips in the CBD and that most buildings in the CBD's of large U.S. cities have no offstreet loading and unloading areas.\textsuperscript{215} He concludes that freight vehicles have lowered the capacity of the city's streets and highways to move both passenger and highway traffic.\textsuperscript{216}

It has been demonstrated that truck transportation in cities is an important factor in the level of noise and air pollution. McDermott estimated that in a nine hour period 660 trucks produced 459 pounds of carbon monoxide, 107 pounds of hydrocarbons and 36 pounds of nitrogen
oxide. Noise pollution studies in New York City have attributed 75 percent of the noise pollution to trucks.

Urban freight transportation is also a large consumer of energy. It is estimated that in 1971 urban trucking consumed three percent of all petroleum used in the U.S.

The effect of the urban freight distribution system on the consumer can be summarized as follows:

"In the end, it is the ultimate consumer who bears the burden of the increasing costs for urban freight distribution. Distribution expenses are treated as pass-through costs by members of the channel of distribution. For example, carriers pass through to the retailer the additional costs of servicing in the central business district, via surcharges and higher rates. The retailer in turn passes these costs through to the ultimate consumer."

It is apparent that urban freight transportation is a significant factor in our society. It accounts for a growing and sizable portion of our GNP and it is particularly significant in the CBD's of our major cities where it is concentrated. Judging by the vehicle capacity utilization reports and others it is also grossly inefficient. These inefficiencies result in increased congestion, pollution, energy consumption and raise the prices of the products of society. It appears that order consolidation by shippers can increase vehicle capacity utilization and reduce the number of vehicle trips and thus help to reduce all of these evils to some extent. It is by no means a total solution to the urban freight distribution problem but it can serve to ease the problem somewhat.
Conclusion

The purpose of this chapter has been to present a comprehensive picture of our current understanding of order consolidation. From this literature review the following conclusions can be drawn:

* The logistics literature has only recently begun to recognize the strategy of order consolidation as a viable alternative to direct LTL shipments, networks based on distribution centers and other strategies.

* The logistics, transportation and traffic management literature has emphasized the cost saving opportunities of order consolidation and the details of certain aspects of consolidation but not in a comprehensive and analytic fashion. The treatment has been merely descriptive.

* An order consolidation system is complex, requiring the consideration of many factors to be properly established, operated and maintained. Many of these factors are listed in Appendix C.

* Order consolidation can be inbound, outbound or both depending on the point of view of the firm.

* The stop-off privilege and its variations—split pickup and delivery, transloading and the marriage rule—can be seen as important methods to achieve consolidation and thus reduce the line-haul transportation charges. Stop-offs also increase the level of complexity present in the system because of the rules governing their use, particularly those affecting the calculation of the line-haul transportation rate. It is interesting to note that the customer service aspects of stop-offs, other than the effect on transit times and the terms of sale, are not discussed or mentioned. Stop-offs may also result in some confusion as to whether a shipment is inter or intra state in nature.

* Consolidation, when it results in a mixed shipment, can increase the complexity of determining the lowest applicable freight rate.

* The maximum capacity of the vehicle need not be the maximum for a consolidated shipment if overflow provisions are available.
If a shipper chooses not to do any or a portion of his consolidation he can join a shippers' association or contract with a shipper's agent. A number of alternatives are available each with unique legal constraints and service capabilities.

The establishment of a consolidation system involves the identification of clusters of demand where breakbulk points can be located. The high volume points can be identified and included in the system quickly, but the medium volume points are more difficult to analyze because of the variability of demand and its effect on the length and variability of the order cycle. The effect of stop-offs on the number of consolidation points is not discussed or even mentioned.

Maximum holding time is presented as an important factor because of its effect on the order cycle. The length of the delay period to establish order consolidation is unclear because of conflicting opinions and very little empirical evidence to support them.

The literature suggests that at least for some firms the establishment of a consolidation system is achieved with limited analysis and trial and error. In addition, breakbulk points and then surrounding service areas and the maximum holding times are chosen arbitrarily. It is suggested that the generally unsophisticated analysis is caused by the absence of a methodology which is suitable for a comprehensive analysis.

There is evidence that many firms in the U.S. have not applied computer technology to the order consolidation problem in either planning or operation of the system. Furthermore, for those firms which have applied data processing techniques to order consolidation the extent of the applications is not known.

Distribution modeling efforts have generally ignored the order consolidation problem or at best treated it incompletely. None of the models developed for the order consolidation problem are suitable for the analysis of the problem as stated in this study. It is interesting to note that the models with some aspects of order consolidation represented are Monte Carlo simulation models while the mathematical programming model assumed the problem away. This is to be expected considering the stochastic and dynamic aspects of the order consolidation problem.
* The viewpoint of the carrier is seen as one of encouraging shippers to consolidate so that its operating costs might be reduced. Order consolidation is seen as a partial solution to the small shipments problem.

* Society's perspective of order consolidation is as a partial solution to the problems of congestion, noise pollution, air pollution and energy consumption in our urban areas.

* Shippers, carriers and society in general can all gain from the adoption of an order consolidation strategy by individual shippers.

In terms of the specific research questions presented in this study there are several very important conclusions which can be drawn from this review of the literature.

1. The relationship of the number of consolidation zones to the cost and service performance of the distribution system has not been investigated.

2. The relationship of the maximum holding time for orders has not been explored in terms of order cycle and variability.

3. The effect of the stop-off provisions on system performance has not been investigated.

4. The relationship of the number of zones, the maximum holding time and the use of stop-offs has not been investigated in terms of system performance.

5. These relationships are important to the efficient and effective operation of an order consolidation system.
Chapter II

Notes


16. Ibid., p. 22.

17. Ibid.


20. Ibid.

21. Ibid.


24. It should be kept in mind that classification ratings approximate a mathematically equivalent relationship. Thus, a class 200 rate will be approximately twice a class 100 rate for shipments in the same territory moving equal distances.

25. Newbourne, p. 3.

26. See Appendix B for rate increases by three rate bureaus.

27. Ibid.


32. Ibid.


34. Dixon, p. 30.


36. Ibid., p. 1

37. Pollock, p. 34.

38. Ibid.


43. Newbourne, pp. 32-34.

44. Ibid., p. 32.

45. Ibid., p. 33.

46. Ibid.

47. Ibid.

48. Ibid.

49. Ibid., p. 27.


51. Newbourne, p. 33.

52. Ibid.


54. Ibid., p. 33.

55. Flood, p. 257.

56. Ibid., p. 258.

57. Taff, p. 347.


59. Ibid.

60. Ibid.

61. Ibid.


63. Flood, p. 272.
64. For example see Central States Motor Freight Bureau, Inc., Tariff 100-F, Item 900-275, Number 2.


66. Ibid.


68. Flood, p. 261.

69. Ibid., pp. 261-262.

70. Tariff 135-C, Item 900.

71. For example see Tariff 135-C, Item 900.

72. Ibid.

73. Flood, pp. 263-268.

74. Ibid., p. 263.

75. Ibid.

76. Ibid.

77. Ibid., p. 264.

78. Ibid.

79. Newbourne, p. 29.

80. For example see Tariff 100-F, Item 900-270.


82. Ibid., p. 265.

83. Ibid.

84. Ibid., p. 266.

85. Ibid.

86. Ibid., p. 109.

87. Ibid. For example see Rule 10 of the Uniform Freight Classification and Rule 130 of the National Motor Freight Classification.

88. See Appendix C for Definition.
89. Flood, p. 109.

90. For example see Tariff 135-C, Item 645.

91. For example see Tariff 100-F, Item 645, Section 1.

92. Ibid.


94. For example see Tariff 100-F, Section 5.

95. Flood, p. 150-151.

96. Ibid., p. 151.

97. Ibid.

98. Newbourne, p. 72.


100. Ibid.

101. Ibid., pp. 119-120.

102. Ibid., p. 53.

103. Ibid., p. 56.

104. Flood, pp. 55-56.

105. Ibid., pp. 56-58.

106. Ibid., pp. 59-61.

107. Ibid.

108. Newbourne, p. 34.

109. Ibid.

110. Ibid.

111. Ibid.


113. Ibid.

114. Ibid.

116. Ibid., p. 305.

117. Ibid.

118. Ibid., p. 306.

119. Ibid.

120. Newbourne, p. 35.

121. Ibid., p. 46.


123. Vreeland, p. 44.

124. Ibid., p. 45.

125. Ibid., p. 43.


128. Ibid., p. 18.

129. Ibid.

130. Newbourne, p. 35.

131. Ibid.

132. Ibid., p. 36.

133. Ibid.

134. Ibid.

135. Ibid.

136. Ibid.

138. Taff, p. 444.

139. Ibid., p. 456.

140. Ibid., p. 98.

141. Ibid.

142. Ibid.

143. Ibid., p. 254.


145. Ibid.

146. Ibid.

147. Ibid.


149. Ibid., p. 42.

150. Ibid.

151. Ibid.

152. Ibid.

153. Ibid.

154. Ibid.

155. Ibid.

156. Ibid., p. 16.

157. Ibid.

158. Ibid., p. 15.


161. Ibid., p.


163. Ibid., p. 88.


165. Newbourne, p. 17.

166. Ibid., p. 44.

167. Ibid., p. 46.

168. Ibid., p. 44.

169. Ibid., p. 46-47.

170. Ibid., p. 47.

171. Ibid.

172. Ibid., p. 49.


174. Ruse, pp. 45-49.

175. Ibid., p. 47.


179. Ibid.


187. Ibid., p. 2.


189. Ibid.
190. Holloway, p. 48.

191. Ibid.


194. Ibid.


196. Ibid., p. 28.

197. Ibid., p. 57.

198. Ibid., p. 25.

199. Ibid., p. 43.

200. Ibid., p. 28.

201. Ibid., p. 41.

202. Ibid., p. 42.

203. Ibid., p. 11.

204. Ibid.


207. Ibid.

208. Newbourne, p. 3.


211. Smith, p. 68.

212. Ibid., p. 16.


216. Ibid.

217. McDermott, p. 68.


220. Ibid., p. 16.
III. RESEARCH METHODOLOGY

Introduction

The research methodology can be described as experimentation using a computer based Monte Carlo/Simulation model. This approach requires the development of a computer based simulation model of a distribution system capable of order consolidation on which experiments are conducted. The experiments are conducted by varying the number of consolidation zones, the use of stop-offs and the maximum number of days an order can be held and measuring the response of the system in terms of total costs, order cycle length and order cycle variability. The responses are then analyzed to determine the importance of the factors themselves, their various levels and their interactions.

This chapter is presented in four sections: (1) formulation of a computer program; (2) validation of the model; (3) the experimental design; and (4) the analysis of the simulated data.

Formulation of the Computer Program

Formulation of the computer program involves a mathematical statement of the problem, the selection of a modeling technique and a programming language, a description of the programming logic, the inputs required by the model and the output of the model.
Mathematical Statement of the Problem

Comparison of the costs incurred in consolidating the groups of orders accumulated over a period of time versus the cost of shipping each one as an LTL shipment can be expressed algebraically. Equation (1) represents the LTL costs for orders destined for points in zone \( j \) during time period \( k \).

\[
\sum_{i=1}^{n} l_{ijk} = L_{jk}
\]

Where: \( l_{ijk} \) = LTL costs of an individual shipment \( i \) destined for consolidation zone \( j \) during time period \( k \).

\( L_{jk} \) = LTL costs of all shipments destined for zone \( j \) during time period \( k \).

Equation (2) expresses the costs of the consolidated shipment for orders moving to points in consolidation zone \( j \) during time period \( k \).

\[
\frac{1}{3} \sum_{i=1}^{n} T_{ijk} + \sum_{i=1}^{n} H_{ijk} + \sum_{i=1}^{n} D_{ijk} + \sum_{i=1}^{n} I_{ijk} + \sum_{i=1}^{n} R_{ijk} - \sum_{i=1}^{n} M_{ijk} = I_{Mijk}
\]

Where: \( T_{ijk} \) = Line-haul transportation costs for movement of order \( i \) to the pool point \( j \) during time period \( k \).

\( H_{ijk} \) = Handling costs for order \( i \) moving through pool point \( j \) during time period \( k \).

\( D_{ijk} \) = Local distribution costs for order \( i \) moving from pool point \( j \) to their final destination during period \( k \).

\( I_{ijk} \) = Inventory carrying costs created by consolidation of order \( i \) moving through pool point \( j \) during time period \( k \).
\[ R_{ijk} = \text{Costs created by reactions of customer to the effects of consolidation of order } i \text{ moving through pool point } j \text{ during time period } k. \]

\[ M_{ijk} = \text{Miscellaneous savings, e.g. reduced loss and damage, due to consolidation of order } i \text{ to pool point } j \text{ during time period } k. \]

\[ C_{jk} = \text{Total costs of a consolidated shipment to pool point } j \text{ during time period } k. \]

The line-haul transportation charges for a consolidated shipment is one rate based on the total weight of the shipment, the type of product(s), whether it is an interstate or intrastate movement, the distance and the carrier. ¹

The pool distributor may levy a handling charge, in addition to a delivery charge² which may be based either on a per hundredweight basis or on a per package basis.³

The local transportation charge is most often made on a per hundredweight basis subject to a minimum amount.⁴ In a pool distribution situation where the shipment crosses the boundary of two or more states that shipment is considered an interstate shipment from origin to ultimate destination and is therefore regulated by the ICC.⁵ If private carriage is used for the line-haul portion of the movement local distribution would be an intrastate movement.⁶

Inventory carrying costs will be affected by order consolidation to the extent that the order cycle time up to invoicing is changed. If there is no change in this portion of the order cycle time then this factor would be equal to zero. If order consolidation delays invoicing the factor would be positive. Inventory carrying costs "should only include those costs that vary with the level of inventory stored and
can be categorized into the following groups: (1) capital costs, (2) inventory service costs, (3) storage space costs, and (4) inventory risk costs. 7

Reaction of customers to the effects of order consolidation is the most difficult of the costs to arrive at and will not be dealt with in this paper in any detail. However, the net effect of order consolidation can be negative or positive. It can reduce the landed cost of the product to the customer but it can also increase the length and variability of the order cycle. The customer will probably react positively to a price reduction, negatively or not at all to an increase in order cycle time and negatively to an increase in order cycle variability. This study will try to measure the changes in these variables as experiments are conducted on different system designs but it will make no effort to predict or estimate customer reaction to these occurrences.

Miscellaneous cost savings refer to the effects of order consolidation on such things as loss and damage to shipments. Order consolidation can be expected to produce a reduction in costs of the consolidation shipment. While these cost savings may be important in some situations they will not be specifically included in this study.

The decision to consolidate is made when the costs of the entire consolidated shipment are less than the costs of sending each shipment directly to its final destination as an LTL movement providing that customer service constraints are observed. Equation (3) summarizes this decision.
(3) If \( C_{jk} < L_{jk} \), then consolidate; otherwise ship LTL

It is important that the total costs of the consolidated shipment be compared to the LTL costs because it is possible that the costs of a single shipment will be increased by inclusion in the consolidated shipment but that this increase is offset by savings to the remainder of the shipment.

A simple hypothetical example will help to explain. Consider a load with two portions—one weighs 10,000 pounds and must be delivered some distance from the breakbulk point while the other weighs 20,000 pounds and will remain at the breakbulk point. Table 3-1 presents the freight charges.

If the 10,000 pound shipment is not consolidated the cost will be $500 (10,000 pounds \( x \) $5.00/cwt). If it is consolidated the total charges will amount to $550 (10,000 pounds \( x \) $3.00/cwt + 10,000 pounds \( x \) $2.50/cwt) or $50 more than sending it at the less than volume rate. On this evidence the best decision would seem to be to ship it singly. However, the effect on the other portion of the shipment must be determined if total costs are to be considered. Therefore, if the 20,000 pounds is consolidated with the 10,000 pounds its freight charges will be $600 (20,000 pounds \( x \) $3.00/cwt). If it is not consolidated it will cost $800 (20,000 \( x \) $4.00/cwt). Thus, by shipping separately, the 10,000 pound portion's costs are lowered $50 while the 20,000 pound portion's costs are increased $200. The lowest cost decision is thus
### TABLE 3-1

**Freight Charges**

- 30,000 lb. volume to breakbulk point = $3.00/cwt
- 20,000 lb. volume to breakbulk point = $4.00/cwt
- 10,000 lb. rate from the breakbulk point to the final destination = $2.50/cwt

### TABLE 3-2

**Summary of Costs**

<table>
<thead>
<tr>
<th></th>
<th>Consolidated</th>
<th>Unconsolidated</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000 lb. line haul</td>
<td>$300</td>
<td>$500</td>
</tr>
<tr>
<td>Beyond break-bulk</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$550</td>
<td>$500</td>
</tr>
<tr>
<td>20,000 lb. line haul</td>
<td>600</td>
<td>800</td>
</tr>
<tr>
<td>Total Costs</td>
<td>$1150</td>
<td>$1300</td>
</tr>
<tr>
<td>Advantage of Consolidation</td>
<td>$150</td>
<td></td>
</tr>
</tbody>
</table>
to consolidate the two orders. Table 3-2 summarizes the costs.

Consolidation results in an overall freight savings of $150.

The decision to add an individual shipment to the consolidated shipment therefore must be made on the basis of the savings to the total shipment, not each individual shipment. If consolidation results in cost savings to the shipment and the costs of the consolidated shipment decrease, consolidation should take place. If, however, the costs to the individual shipment are raised by consolidation without an offsetting decrease in costs to the consolidated shipment, consolidation should not occur. This decision process can be expressed as a series of inequalities:

\[
\begin{align*}
\text{If } X_c - X \ell &< 0 \text{ consolidate} \\
\text{If } X_c - X \ell > 0 \text{ and } (X_c - X \ell) < (C_{jk} - C_{j\ell}) \text{ ship } X \text{ LTL}, & \text{ otherwise consolidate}
\end{align*}
\]

Where:

- \( X_c \) = Shipment X's costs if consolidated
- \( X \ell \) = Shipment X's costs if shipped LTL
- \( C_{jk} \) = Costs of consolidated shipment without shipment X
- \( C_{j\ell} \) = Costs of consolidated shipment with shipment X

The addition of stop-offs expands equation (2) since there will be a stop-off charge and a handling and local distribution charge for the orders moving through the stop-off point which may be different from the costs associated with the other point. The handling and local
transportation charges must be summed over more than one destination. In addition, stop-offs are usually limited to three plus the final destination therefore incurring a charge for all stops over one. 9

\[
(4) \sum_{i=1}^{n} T_{ijk} + \sum_{i=1}^{n} \sum_{j=1}^{n} H_{ijk} + \sum_{i=1}^{n} \sum_{j=1}^{n} D_{ijk} + \sum_{i=1}^{n} R_{ijk} - \\
\sum_{i=1}^{n} M_{ijk} + \sum_{j=2}^{n} S_{jk} = C_{jk}
\]

Where \( S_{jk} \) = Stop-off charge at point \( j \) during time period \( k \)

The line-haul transportation charges may change with the addition of a stop-off. The rate will be that to the highest rated point which is usually the final estination but not always. 10 Also, there is usually a circuitry restriction which penalizes the shipper who adds stop-offs which lengthen the total distance traveled by a specified factor over the short line distance from origin to final destination. 11

The use of the stop-off privilege must be used judiciously. If the cost of the consolidated shipment with the stop-off is less than the cost of the consolidated shipment without the stop-off plus the cost of the LTL shipment to the stop-off point the stop-off should be used.
Equation (5) expresses the decision to use the stop-off as:

\[
(5) \quad \text{If } C_h < C + L_h \text{ use the stop-off, otherwise ship separately}
\]

Where

\[
C_h = \text{Cost of the consolidated shipment including the stop-off at point } h
\]

\[
C = \text{Cost of consolidated shipment without stop-off}
\]

\[
L_h = \text{Cost of the LTL shipment to point } h
\]

It should be pointed out that the stop-off privilege will only be used if the orders destined for one of the points cannot be held any longer.

The Modeling Technique

A computer based Monte Carlo/Simulation model was chosen as the vehicle for this research for several reasons. First, such a model can be manipulated in ways which are impossible, too expensive and impractical to perform on an actual distribution system.12

Second, the problem of order consolidation has been presented as one consisting of a number of stochastic processes including transit times, order sizes and order receipt times. Naylor states that

"Because stochastic models are considerably more complex than deterministic models, the adequacy of analytical techniques for obtaining solutions to these models is quite limited. For this reason simulation is much more attractive as a method for analyzing and solving stochastic models than deterministic models."13

The fact that a number of the operating characteristics of the order consolidation system are given by probability functions indicates that
simulation is preferable to deterministic analytic techniques.

Next, a model of an order consolidation system must explicitly take into account the variable time. The importance of the variable time to order consolidation can be seen in terms of the maximum holding time allowed for orders and that the effects of events occurring today will be felt in the future. For example, the size of a particular shipment today may depend on the number of orders destined for that particular area which were received in some preceding time period. Naylor would classify an order consolidation system as dynamic because it deals with time-varying interactions.\textsuperscript{14} Simulation has been widely used to model dynamic economic systems because such systems are usually also stochastic.\textsuperscript{15}

The Monte Carlo/Simulation technique is therefore the preferred modeling technique since an order consolidation system is both stochastic and dynamic.

The Model

The basic model is programmed in FORTRAN and is discussed in reference to the flow chart in Figure 3-1. The model is composed of three major components 1) the order generator 2) the shipping module and 3) the receiving module.

Beginning each simulated day, a predetermined number of orders are generated. The weights and destinations of each order is determined probabilistically. Next, the order is assigned to a predetermined pool
Figure 3-1  Model Flow Chart
Figure 3-1 (Continued)
point and their weight is added to that pool. Orders not assigned to a pool point are shipped LTL direct. Once the weight and destination of the order are determined and it is assigned to a pool point it is stored in an active order file. Once the prescribed number of orders is created processing moves to the shipment module.

In the shipment module each order is examined to determine if it should be shipped. All orders not assigned to a pool point are shipped LTL direct the same day they are created. If it is a ship day, all orders are shipped. If it is not a ship day processing moves to the next component. If an order is shipped its arrival date at the customer's location and the freight charges must be determined.

Arrival dates require that the transit time be calculated in days and added to the current date. Transit times are calculated using a series of equations developed from a study of Department of Defense transit times by Piercey.\(^\text{18}\) The exact transit time depends on the weight of the order and the distance from the plant to the pool point, if applicable, and to the final destination. TL shipments travel faster than LTL shipments.\(^\text{19}\)

Transportation charges are determined by calculating the actual class rates for each portion of the trip. TL shipments are rated class 70 while LTL shipments are rated class 100.

Once all the appropriate orders have been shipped processing moves to the next module. At this point the active order file is searched for
Figure 3-2 Flow Chart of Stop-Off Logic
orders due to arrive today. If the order is due today it is transferred to the output file. Once all of the orders due to arrive today are processed, a new day begins and the sequence of events described above begins anew.

Stop-offs are treated separately according to the flow chart in Figure 3-2.

The stop-off module is run after all consolidated shipments are released. It tries to construct stop-offs from the order queues which are too small for a TL and cannot be held any longer. Any other order queue can be used to facilitate the construction of a consolidated load.

The stop-off table data file is the basis for stop-off construction. It is a user specified list of the points which can be considered together for possible stop-offs. If there are no points with orders which can be considered for a stop-off, the order is shipped LTL.

The stop-off point providing the greatest savings per pound is included in the shipment until a TL quantity is reached or until no more order queues are available for consideration. If the combination of the last order queue exceeds the vehicle's capacity, the youngest orders with the least savings are returned to the order queue if savings are still available from the trimmed order queue.

**Inputs to the Model**

There are a number of requirements which must be met from outside the model.
Figure 3-3  Percentage of Orders by Weight Received by the Model Firm
Order Generation

In order to generate orders the model must be supplied with the following data:

(1) The number of orders to be generated each day.

(2) The number of days the model is to run.

(3) The order weight distribution which will be sampled by way of a random number generator to determine the weight of the order. The distribution of order weights used in this study was developed from data supplied by a medium sized producer of packaged consumer goods. The order weight distribution is presented in Figure 3-3. The average order size is 1300 pounds.

(4) The percentage of the population residing in each market is required to determine the destination of the order. This distribution is sampled by way of a random number generator.

Pool Points

Pool points were ranked on the basis of greatest savings. Thus, the largest and most distant were chosen first. Markets were assigned to these pool points if the average order could be shipped least expensively through them. If LTL was cheaper the market was not assigned a pool point.

Freight Rates

Actual class freight rates were used to determine transportation costs from the plant to the pool point and then to the market if a consolidated shipment. If the shipment was LTL direct only the freight rate from plant to market was determined.
Mileages

Mileages are necessary to calculate transit times. The miles linking the plant with all possible pool points and all possible pool points with all of the markets is required.

Stop-off Points

The user must specify which points can be considered together to and from stop-offs. The possible stop-off combinations are input to the model as a table as are the maximum number of stop-offs allowed by the tariff applying to the particular set of points.
**Outputs**

There are three outputs of the model: (1) the average order cycle time per order, (2) the variance of the order cycle times and (3) the total system cost. Order cycle time is defined for the purposes of this study as beginning with the receipt of the order and ending with delivery at the final destination. It therefore includes the time used to consolidate orders and time in transit.

**Validation**

The model will be validated or at least the level of confidence in its operation increased in three steps.

The first step is to be assured that the model design accurately portrays a consolidation system. In other words, are the relationships in the model as they should be theoretically?

The second step involves a detailed check of the operations of the model. This involves feeding through small amounts of data, the results of which are known. This could be called verification of the model or gaining confidence that the model is doing what the modeler wishes. During this stage the detailed mechanics of the model are investigated and adjusted if necessary.

A final test is to run the model using the order generator and analyzing the results for their reasonableness. Expert opinion should be solicited for this step.

If, through each of these steps of validation the model has performed adequately, confidence in it will be sufficiently high to continue on to the experimentation stage.
**Experimental Design**

There are three major factors each with a number of levels. The response of the system to the various levels of these factors will be measured in terms of total system costs, order cycle time and order cycle variability.

The experimental design is presented in Figure 3-4. The number of consolidation zones is increased from zero to 150 in increments of thirty. Zero consolidation zones refers to a system which does no consolidating of orders but rather ships all orders immediately as LTL shipments. The maximum number of 150 zones was chosen because it was felt that 150 is a practical limit to the number of zones a firm would ever consider for the continental U.S. One hundred fifty zones would leave very little of the U.S. without a consolidation point nearby. Furthermore, a ranking of U.S. metropolitan areas by population after the 150th leaves centers of only minor significance in terms of demand for most packaged consumer goods. Varying the number of zones by increments of thirty is felt to be small enough to adequately investigate the relationship of the number of zones to system performance and yet not enlarge the experiments beyond a reasonable number.

The maximum number of holding days allowed ranges from none, or shipping immediately, up to an unlimited number of days allowed. A maximum holding time of 90 days will be considered unlimited assuming that holding an order to achieve consolidation would be very unrealistic for a firm distributing packaged consumer goods. At some number of days
<table>
<thead>
<tr>
<th>Max. Hold Time</th>
<th>No Consolidation</th>
<th>30 Zones</th>
<th>60 Zones</th>
<th>90 Zones</th>
<th>120 Zones</th>
<th>150 Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n Days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unlimited</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3-4 Experimental Design
the response of the system to a specific maximum holding time will be the same as for an unlimited holding time. Unfortunately, it is not known at what point this convergence will take place. Therefore, the unlimited holding time experiments will be run first and then beginning with unlimited holding time will be increased by one day up to n days at which point it is statistically obvious (95% probability) that the results for both are from the same distribution. This will have to be true across all levels of consolidation zones.

The effect of stop-offs will be measured by testing each combination of maximum holding time allowed with the number of consolidation zones with and without stop-offs.

The Generation and Analysis of the Simulated Data

The analysis of simulated data consists of three steps:

1) generation of the data
2) hypothesis testing using Analysis of Variance (ANOVA)
3) multiple comparisons if the null hypotheses are rejected.

Generation of the Data

Data generation involves the initialization of the model, determining the number of observations or runs per call and running the model.

Initialization

Prior to collecting data from the model it is important that a steady state or normal operating condition is attained so that the transient effects of the initial startup of the model do not affect the results.
The model will be started up "empty." That is, there will be no orders in the system until it is started up and the order generator begins operation. Startup will last a period of time equal to twice the maximum holding time of that particular run. The data will then begin to be collected. An initialization period of that duration will allow all consolidation queues to have shipped at least once and for a number of orders to be in the system which is representative of a normal operating condition.

**Number of Observations Per Cell**

The objective in determining the sample size is to achieve the desired level of precision and yet minimize the cost of operating the model. The approach taken in this thesis is to conduct a pilot study of cells selected at random to estimate the standard deviation of the sample and an acceptable error of the estimate. Once these statistics are estimated they will be used in the following formula to obtain the sample size per cell:

\[ n = \frac{(\sigma Z_{\alpha/2})^2}{d^2} \]

Where,
- \( n \) = sample size
- \( Z_{\alpha/2} \) = standardized normal statistic
- \( \sigma \) = standard deviation
- \( d \) = error of the estimate

Once the model is initialized the model will be run the number of times indicated by the above formula changing the random number generation seed so that identical runs will not be made. Three measures of
performance will be collected per run: (1) cost per hundredweight (2) average order cycle time and (3) order cycle variance.

**Running the Model**

Each run will be equal to fifty days of simulated time. A longer period of time would not add significantly to the information obtained from the model especially since demand is represented as nonseasonal.

The sequence of the experiments is based on the difficulty of supplying input requirements to the model. The number of consolidation zones or points is the most difficult and cumbersome factor to change and the maximum holding time is the easiest. Therefore, once the model is set up to run with a certain number of zones all levels of maximum holding time, first without and then with stop-offs, will be run. A maximum holding time of 90 days (assumed to be equal to unlimited holding time) will be run first, then same day, one day, two days and so on until the responses are not significantly different from those obtained with a 90 day holding time. The experiments will begin with 150 zones and work back to "no consolidation" because it is assumed that the lengthier holding times will be the most significant when there are many zones.

**Hypothesis Testing**

Once the simulated data is collected the null hypotheses developed in Chapter I must be tested. Analysis of variance (ANOVA) will be the technique of analysis. The null hypotheses will be rejected at the .05 level. It should be pointed out that ANOVA from a mathematical point of
view is very similar to regression analysis. For example, an analysis of variance can be performed as a regression analysis using dummy variables with zero or one values.

The basic strategy is to test the main effects and the interactions for differences in their means. If significant differences (.05 level) are found the sample means will be ranked using Scheffe's technique of multiple comparisons. This technique is used because it provides a measure of confidence that the sample rankings are not due to random error but are with some probability the true rankings of the population means. It is the results of the rankings that provide insight into the differences indicated by the F-test. The ranking process provides an indication of the direction of the effects.

The Main Effects

The main effects refer to tests for differences between the three major factors-number of consolidation zones, use of stop-offs, and maximum holding days—and the grand mean. The main effect for a particular row or column is the deviation of the corresponding row or column mean from the grand mean.

It should be noted that the analysis will be conducted for each of the three performance measures—cost per hundredweight, average order cycle length and the variance of the order cycle. There is in effect three sets of the experimental design presented in Figure 3-4.
$H_01$ through $H_03$. The main effect of increasing the number of consolidation zones will be analyzed by testing for differences in the column means without regard to the use of stop-offs. In other words the stop-off columns corresponding to a particular number of zones will be added together in order to test for the effects of the number of consolidation zones. If differences in the means are determined by the F-test the sample means will be ranked. If the effect of the number of zones is significant the performance measures will either rise or fall as the number of zones is increased.

$H_04$ through $H_06$. The main effect of the maximum holding time on system performance will be determined by the row totals. If differences in the means are determined by an F-test to exist the means will be ranked.

$H_07$ through $H_09$. The main effect of stop-offs will be analyzed by collapsing together all columns with stop-offs and comparing them to one column of all cells without stop-offs. If the two means are not significantly different, stop-offs can be considered to have little effect on system performance.

**Factor Interactions**

The interaction effects can be described as the "difference between a cell mean and the value predicted from the grand mean and the main effects." In other words, the interaction effect is over and above the "average" effect of the individual factors. "Thus, the absence of interaction means that the effect it has on the response may be studied and measured separately for each of the factors, and these separate or
independent determinations may be used to predict the response at any combination of levels for the factors in question."^28

\( \text{H}_0\text{10 through } \text{H}_0\text{12} \). The first interaction to be analyzed will be that of increased zones and increased maximum holding times. This will require the collapsing of the stop-off and no stop-off cells corresponding to each combination of consolidation zones and maximum number of holding days allowed. If a significant difference in the sample means is found they will be ranked.

\( \text{H}_0\text{13 through } \text{H}_0\text{15} \). The second interaction to be analyzed will be that of the number of zones and the use of the stop-off privilege. This will require that the matrix be collapsed across the maximum number of holding days. If the F-test indicates a significant difference the means will be compared and ranked.

\( \text{H}_0\text{16 through } \text{H}_0\text{18} \). The third two-factor interaction is that of the maximum holding time with the use of the stop-off privilege. This requires collapsing the columns into a single column with stop-offs and one without stop-offs. Differences will be ranked in this case too.

\( \text{H}_0\text{19 through } \text{H}_0\text{21} \). The final interaction to be tested will be a three factor interaction of the number of zones, the maximum holding time and the use of the stop-off privilege. Again, a finding of a significant interaction will necessitate a comparison of the cells.
Chapter III

Notes


2. Unpublished list of pool distributors and their charges used by Anchor Hocking Corporation.

3. Ibid.

4. Ibid.

5. Flood, p. 56.

6. Ibid., p. 57.


9. For example see Tariff S-236-D, Section 2, Rule 2.

10. Flood, p. 262.

11. Ibid.


15. Ibid.


20. This step combines the rational and empirical approaches to verification in the sense that the basic set of assumptions underlying the behavior of the system are indeed facts. A discussion of these approaches is presented by Thomas H. Naylor and J.M. Finger in "Verification of Computer Simulation Models," Management Science 14 (October 1967): 92-101.


22. Ibid., p. 186.


24. Ibid.


27. Ibid., p. 17.

28. Ibid., p. 18.
IV. RESEARCH FINDINGS

This chapter presents the research findings from the model experiments. The experimental factors and their levels are as follows:

1. Number of pool points
   a. Zero or LTL direct
   b. 10 pool points
   c. 30 pool points
   d. 50 pool points
   e. 70 pool points

2. Number of orders entering the system daily
   a. 50 orders
   b. 200 orders

3. Shipment Release Strategy
   a. Scheduled sailing
   b. Scheduled sailing and volume

4. Number of days orders can be held
   a. 1 day
   b. 4 days
   c. 7 days
   d. 10 days

The results of the experiments in terms of the average cost per order, the average order cycle length and the variance of the order cycle are presented for the main effects and the two way interactions. The revised experimental design is presented in Figure 4-1.

The original research proposal was to investigate the following research questions:
<table>
<thead>
<tr>
<th>Scheduled Shipping Interval</th>
<th>LTL Direct</th>
<th>10 Pools</th>
<th>30 Pools</th>
<th>50 Pools</th>
<th>70 Pools</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Day</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Days</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Days</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Days</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4-1  Revised Experimental Design
1. How does increasing or decreasing the number of consolidation points affect the average costs per order, the average order cycle length and the variability of the order cycle?

2. How does increasing or decreasing the maximum holding time for orders affect the average cost per order, the average order cycle length and the variability of the order cycle?

3. How does the use of the stop-off privilege affect the average cost per order, the length of the average order cycle and the variability of the order cycle?

4. How do the number of pool points, the maximum allowed holding time and the use of stop-offs interact to affect average costs per order, average order cycle time and the variability of the order cycle?

The proposed factors and their levels were as follows:
1. Number of Pool Points
   a. No pool points
   b. 60 pool points
   c. 90 pool points
   d. 120 pool points
   e. 150 pool points

2. Number of Days Orders Can Be Held
   a. 1 day
   b. 2 days
   c. n days
   d. Unlimited

3. Stop-off to Unload
   a. No stop-offs
   b. Stop-offs

It can be seen in comparing the actual factors and their levels with the proposed factors and their levels that a number of modifications were made to the research design. The major modification to the study was to drop stop-offs from consideration and to add two levels of daily order volume, 50 and 200 orders per day, and two shipment release strategies, scheduled sailing and scheduled sailing with volume, to the study. Less significant changes involved revising the number of pool points from 0, 60, 90, 120 and 150 to a more realistic 0, 10, 30, 50 and 70. Also, the maximum number of days orders could be held to achieve consolidation was changed to 1, 4, 7 and 10 from one day up to a number equal to an unlimited number of days. The maximum number of days held is equivalent to the length of the scheduled shipping interval. The reasons for these modifications are fully discussed in Chapter IV.

The results of the tests of the null hypotheses proposed in Chapter I are presented first as experimental findings. The new factors
are presented next as other findings and the cell means of all three dependent variables are presented in figures 4-23, 4-24 and 4-25 at the end of the chapter.

Interpretation of Findings

To facilitate the interpretation of the research findings it is necessary to more fully describe the dependent variables, average order cycle time and order cycle variance.

Order cycle time in this study refers to the number of days from the time the order is received by the system until it is delivered to the customer. Average order cycle time is the average number of days from receipt to delivery for all orders whether consolidated or not.

Order cycle variance is the statistical variance for all orders in the system which was determined using the following standard formula:

\[ s^2 = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \]

where 
- \( s^2 \) = sample variance
- \( x_i \) = the value of the ith observation
- \( \bar{x} \) = the sample mean
- \( n \) = the sample size

The variance is a measure of how spread out the order cycle times were, for all orders, from the mean order cycle time.
It should be noted that the measure used here is different from that traditionally used by a distribution manager to measure the consistency of customer service. It is different in two ways. First, it measures the time from receipt of the order until delivery at the final destination, not just transit time. Secondly, it is an overall measure. It includes all orders in the system not just those moving between two given geographic points.

Experimental Findings

The null hypotheses developed to provide answers to the research questions were tested by analyzing the results of the model experiments using Analysis of Variance (ANOVA) and Scheffe's multiple comparison technique. The hypotheses and research findings are presented below.

**Experiment 1 (H₀₁)**

Hypothesis 1 was designed to test the effect of the number of pool points on average costs.

\[ H₀₁ \text{ Increasing the number of consolidation points from zero to 10 to 30 to 50 to 70 will have no effect on the average costs per order.} \]

The effect of the number of pools on the average cost per order was found to be highly significant as can be seen from the Analysis of Variance (ANOVA) presented in Table 4-1.

As can be seen from the graph in Figure 4-2 the general effect of increasing the number of consolidation points is to increase costs.
Figure 4-2: Effect of Number of Pools on Average Cost Per Shipment
Figure 4-3 The Effect of the Number of Pool Points on Average Order Cycle Time.
In fact, only the network with 10 points is below the costs of shipping all orders LTL. As will be shown and discussed later the increase in costs as pool points are added is primarily a function of the number of orders entering the system daily and the length of the shipping interval. A comparison of the group means in the graph using Scheffe's technique indicates that at the .01 level the average cost per order at the 10 pool point level and at the 70 pool point level are significantly different. In view of these results $H_01$ is rejected.

Experiment 2 ($H_02$)

Hypothesis 2 was designed to test the effects of the number of pool points on the average order cycle.

$H_02$ Increasing the number of consolidation points from zero to 10 to 30 to 50 to 70 will have no effect on the length of the average order cycle.

The effect of the number of pools on the length of the order cycle was found to be significant at the .001 level as can be seen from the analysis of variance results presented in Table 4-2. Therefore, the null hypotheses $H_02$ is rejected.

The graph in Figure 4-3 demonstrates that as the number of pools increases so does the average order cycle time. A comparison of group means using Scheffe's technique found that the order cycle time with ten pools was significantly different from the order cycle times for 30, 50 and 70 pools at the .01 level. Order cycle time at 30, 50 and 70 pools was not found to be significantly different.
TABLE 4-1

Results of the Analysis of Variance of Average Cost Per Order By the Number of Pools, the Number of Orders, the Shipment Release Strategies Used and the Scheduled Shipping Interval.

<table>
<thead>
<tr>
<th>SOURCE OF VARIATION</th>
<th>SUM OF SQUARES</th>
<th>DF</th>
<th>MEAN SQUARE</th>
<th>F</th>
<th>SIGNIF-OF F</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN EFFECTS</td>
<td>41877.875</td>
<td>8</td>
<td>5234.734</td>
<td>380.379</td>
<td>0.01</td>
</tr>
<tr>
<td>POOLS</td>
<td>3158.995</td>
<td>3</td>
<td>1052.998</td>
<td>76.515</td>
<td>0.0001</td>
</tr>
<tr>
<td>ORDERS</td>
<td>15391.430</td>
<td>1</td>
<td>15391.430</td>
<td>1118.408</td>
<td>0.01</td>
</tr>
<tr>
<td>STRATEGY</td>
<td>230.093</td>
<td>1</td>
<td>230.093</td>
<td>16.720</td>
<td>0.0001</td>
</tr>
<tr>
<td>SHIPPING INTERVAL</td>
<td>23097.355</td>
<td>3</td>
<td>7699.117</td>
<td>559.451</td>
<td>0.01</td>
</tr>
<tr>
<td>2-WAY INTERACTIONS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POOLS ORDERS</td>
<td>1515.373</td>
<td>3</td>
<td>505.124</td>
<td>36.705</td>
<td>0.0001</td>
</tr>
<tr>
<td>POOLS STRATEGY</td>
<td>88.327</td>
<td>3</td>
<td>29.442</td>
<td>2.139</td>
<td>0.096</td>
</tr>
<tr>
<td>POOLS INTERVAL</td>
<td>1911.939</td>
<td>9</td>
<td>212.438</td>
<td>15.437</td>
<td>0.0001</td>
</tr>
<tr>
<td>ORDERS STRATEGY</td>
<td>207.715</td>
<td>1</td>
<td>207.715</td>
<td>15.094</td>
<td>0.0001</td>
</tr>
<tr>
<td>ORDERS INTERVAL</td>
<td>53.831</td>
<td>3</td>
<td>17.943</td>
<td>1.304</td>
<td>0.274</td>
</tr>
<tr>
<td>STRATEGY INTERVAL</td>
<td>175.430</td>
<td>3</td>
<td>58.477</td>
<td>4.249</td>
<td>0.006</td>
</tr>
<tr>
<td>3-WAY INTERACTIONS</td>
<td>1223.672</td>
<td>24</td>
<td>50.986</td>
<td>3.705</td>
<td>0.001</td>
</tr>
<tr>
<td>POOLS ORDERS STRATEGY</td>
<td>176.346</td>
<td>3</td>
<td>58.782</td>
<td>4.271</td>
<td>0.006</td>
</tr>
<tr>
<td>POOLS ORDERS INTERVAL</td>
<td>304.782</td>
<td>9</td>
<td>33.865</td>
<td>2.461</td>
<td>0.011</td>
</tr>
<tr>
<td>POOLS STRATEGY INTERVAL</td>
<td>627.263</td>
<td>9</td>
<td>69.696</td>
<td>5.064</td>
<td>0.001</td>
</tr>
<tr>
<td>ORDERS STRATEGY INTERVAL</td>
<td>115.280</td>
<td>3</td>
<td>38.427</td>
<td>2.792</td>
<td>0.041</td>
</tr>
<tr>
<td>4-WAY INTERACTIONS</td>
<td>315.520</td>
<td>9</td>
<td>35.058</td>
<td>2.547</td>
<td>0.008</td>
</tr>
<tr>
<td>POOLS ORDERS STRATEGY INTERVAL</td>
<td>315.519</td>
<td>9</td>
<td>35.058</td>
<td>2.547</td>
<td>0.008</td>
</tr>
<tr>
<td>EXPLAINED</td>
<td>47369.684</td>
<td>63</td>
<td>751.900</td>
<td>54.636</td>
<td>0.01</td>
</tr>
<tr>
<td>RESIDUAL</td>
<td>3523.047</td>
<td>256</td>
<td>13.762</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>50892.730</td>
<td>319</td>
<td>159.538</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 4-2

Results of the Analysis of Variance of Average Order Cycle Time by the Number of Pool Points, the Shipment Release Strategy Used, the Scheduled Shipping Interval and the Number of Orders Entering the System Daily.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum of Squares</th>
<th>DF</th>
<th>Mean Square</th>
<th>F</th>
<th>Signif. of F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pools</td>
<td>54.907</td>
<td>3</td>
<td>18.302</td>
<td>2578.081</td>
<td>0.01</td>
</tr>
<tr>
<td>Orders</td>
<td>116.377</td>
<td>1</td>
<td>116.377</td>
<td>16625.285</td>
<td>0.01</td>
</tr>
<tr>
<td>Strategy</td>
<td>3.570</td>
<td>1</td>
<td>3.570</td>
<td>502.861</td>
<td>0.01</td>
</tr>
<tr>
<td>Shipping Interval</td>
<td>36.088</td>
<td>3</td>
<td>12.029</td>
<td>1694.494</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>2-Way Interactions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pools Orders</td>
<td>6.293</td>
<td>3</td>
<td>2.098</td>
<td>295.491</td>
<td>0.01</td>
</tr>
<tr>
<td>Pools Strategy</td>
<td>0.298</td>
<td>3</td>
<td>0.099</td>
<td>13.989</td>
<td>0.0001</td>
</tr>
<tr>
<td>Pools Interval</td>
<td>8.789</td>
<td>9</td>
<td>0.977</td>
<td>137.553</td>
<td>0.01</td>
</tr>
<tr>
<td>Orders Strategy</td>
<td>1.797</td>
<td>1</td>
<td>1.797</td>
<td>253.148</td>
<td>0.0001</td>
</tr>
<tr>
<td>Orders Interval</td>
<td>26.742</td>
<td>3</td>
<td>8.914</td>
<td>1255.633</td>
<td>0.01</td>
</tr>
<tr>
<td>Strategy Interval</td>
<td>6.614</td>
<td>3</td>
<td>2.205</td>
<td>310.566</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>3-Way Interactions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pools Orders Strategy</td>
<td>0.369</td>
<td>3</td>
<td>0.123</td>
<td>17.341</td>
<td>0.0001</td>
</tr>
<tr>
<td>Pools Orders Interval</td>
<td>4.954</td>
<td>9</td>
<td>0.550</td>
<td>77.537</td>
<td>0.0001</td>
</tr>
<tr>
<td>Pools Strategy Interval</td>
<td>0.334</td>
<td>9</td>
<td>0.037</td>
<td>5.232</td>
<td>0.0001</td>
</tr>
<tr>
<td>Orders Strategy Interval</td>
<td>3.760</td>
<td>3</td>
<td>1.253</td>
<td>176.557</td>
<td>0.0001</td>
</tr>
<tr>
<td><strong>4-Way Interactions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pools Orders Strategy Interval</td>
<td>0.331</td>
<td>9</td>
<td>0.037</td>
<td>5.181</td>
<td>0.0001</td>
</tr>
<tr>
<td><strong>Explained</strong></td>
<td>271.223</td>
<td>63</td>
<td>4.305</td>
<td>606.429</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Residual</strong></td>
<td>1.817</td>
<td>256</td>
<td>0.007</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>273.041</td>
<td>319</td>
<td>0.856</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 4-3

Results of the Analysis of Variance of Order Cycle Variance by the Number of Pool Points, the Release Strategy Used, the Scheduled Shipping Interval, and the Number of Orders Entering the System Daily.

<table>
<thead>
<tr>
<th>SOURCE OF VARIATION</th>
<th>SUM OF SQUARES</th>
<th>DF</th>
<th>MEAN SQUARE</th>
<th>F</th>
<th>SIGNIF. OF F</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN EFFECTS</td>
<td>4417.332</td>
<td>8</td>
<td>552.167</td>
<td>1885.514</td>
<td>0.01</td>
</tr>
<tr>
<td>POOLS</td>
<td>400.975</td>
<td>3</td>
<td>133.658</td>
<td>456.411</td>
<td>0.01</td>
</tr>
<tr>
<td>ORDERS</td>
<td>1204.292</td>
<td>1</td>
<td>1204.292</td>
<td>4112.359</td>
<td>0.01</td>
</tr>
<tr>
<td>STRATEGY</td>
<td>85.349</td>
<td>1</td>
<td>85.349</td>
<td>291.446</td>
<td>0.01</td>
</tr>
<tr>
<td>SHIPPING INTERVAL</td>
<td>2726.718</td>
<td>3</td>
<td>908.906</td>
<td>3103.692</td>
<td>0.01</td>
</tr>
<tr>
<td>2-WAY INTERACTIONS</td>
<td>993.074</td>
<td>22</td>
<td>45.140</td>
<td>154.141</td>
<td>0.01</td>
</tr>
<tr>
<td>POOLS ORDERS</td>
<td>23.108</td>
<td>3</td>
<td>7.703</td>
<td>26.302</td>
<td>0.0001</td>
</tr>
<tr>
<td>POOLS STRATEGY</td>
<td>0.788</td>
<td>3</td>
<td>0.263</td>
<td>0.897</td>
<td>0.443</td>
</tr>
<tr>
<td>POOLS INTERVAL</td>
<td>205.625</td>
<td>9</td>
<td>22.847</td>
<td>78.018</td>
<td>0.0001</td>
</tr>
<tr>
<td>ORDERS STRATEGY</td>
<td>5.722</td>
<td>1</td>
<td>5.722</td>
<td>19.539</td>
<td>0.0001</td>
</tr>
<tr>
<td>ORDERS INTERVAL</td>
<td>627.167</td>
<td>3</td>
<td>209.056</td>
<td>713.875</td>
<td>0.01</td>
</tr>
<tr>
<td>STRATEGY INTERVAL</td>
<td>130.664</td>
<td>3</td>
<td>43.555</td>
<td>148.728</td>
<td>0.0001</td>
</tr>
<tr>
<td>3-WAY INTERACTIONS</td>
<td>113.211</td>
<td>24</td>
<td>4.717</td>
<td>16.108</td>
<td>0.01</td>
</tr>
<tr>
<td>POOLS ORDERS STRATEGY INTERVAL</td>
<td>11.516</td>
<td>3</td>
<td>3.839</td>
<td>13.109</td>
<td>0.0001</td>
</tr>
<tr>
<td>POOLS ORDERS INTERVAL</td>
<td>44.714</td>
<td>9</td>
<td>4.968</td>
<td>16.965</td>
<td>0.0001</td>
</tr>
<tr>
<td>POOLS STRATEGY INTERVAL</td>
<td>44.945</td>
<td>9</td>
<td>4.994</td>
<td>17.053</td>
<td>0.0001</td>
</tr>
<tr>
<td>ORDERS STRATEGY INTERVAL</td>
<td>12.034</td>
<td>3</td>
<td>4.011</td>
<td>13.698</td>
<td>0.0001</td>
</tr>
<tr>
<td>4-WAY INTERACTIONS</td>
<td>43.379</td>
<td>9</td>
<td>4.820</td>
<td>16.459</td>
<td>0.0001</td>
</tr>
<tr>
<td>POOLS ORDERS STRATEGY INTERVAL</td>
<td>43.379</td>
<td>9</td>
<td>4.820</td>
<td>16.459</td>
<td>0.0001</td>
</tr>
<tr>
<td>EXPLAINED</td>
<td>5566.996</td>
<td>63</td>
<td>88.365</td>
<td>301.745</td>
<td>0.01</td>
</tr>
<tr>
<td>RESIDUAL</td>
<td>74.969</td>
<td>256</td>
<td>0.293</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>5641.965</td>
<td>319</td>
<td>17.686</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Experiment 3 \((H_0.3)\)

Hypothesis 3 was designed to test the effect of the number of pool points on order cycle variance.

\(H_0.3\) Increasing the number of consolidation points from zero to 10 to 30 to 50 to 70 will have no effect on the variance of the order cycle.

The effect of the number of consolidation points in the system on the variance of the order cycle was found to be significant at the .001 level as presented in Table 4-3.

As can be seen from the graph of cell means in Figure 4-4 the order cycle variance increases from no consolidation up to 30 points and then levels off and even decreases somewhat at 50 and 70 pools. LTL direct is less variable at all pool point levels. A comparison of these cell means using Scheffe's technique of multiple comparisons reveals that at the .01 level there is no significant difference between the order cycle variance cell means at 30, 50 and 70 pool points but that they are significantly different than the variance at 10 pool points.

Due to the very high level of significance attributed to this factor in the analysis of variance, null hypothesis 3 is rejected.

Experiment 4 \((H_0.4)\)

Hypothesis 4 was designed to test the effect of increasing the shipping interval on average costs.

\(H_0.4\) Increasing the maximum holding time for orders from one day to 4 days to 7 days to 10 days will have no effect on the average cost per order.
Figure 4-4  The Effect on Order Cycle Variance of the Number of Pool Points in the System
Figure 4-5 presents the effect of varying the scheduled sailing interval on average costs per order. In general, average costs per order decline as the time interval between shipments increases. A comparison of the cell means using Scheffe's technique groups the four means into three significant subsets at the .01 level. These significant subsets are 1) one day, 2) four and seven days and 3) 10 days.

The analysis of variance presented in Table 4-1 indicates that this factor is significant beyond the .05 level and therefore null hypothesis 4 is rejected.

**Experiment 5 (H₀5)**

Hypothesis 5 was designed to test the effect of increasing the shipping interval on the average order cycle.

\[ H₀ 5 \quad \text{Increasing the maximum holding time for orders from one day to 4 days to 7 days to 10 days will have no effect on the length of the average order cycle.} \]

The effect of scheduled sailing intervals on average order cycle time in days is presented in Figure 4-6. Average order cycle time increases as the sailing interval increases. A comparison of the cell means using Scheffe's technique groups the means into three significantly different subsets at the .01 level, which are 1 and 4 days, 4 and 7 days and 7 and 10 days. The analysis of variance presented in Table 4-2 indicates that this relationship is significant at the .001 level. Therefore, null hypothesis 5 is rejected.
Figure 4-5  The Effect of the Scheduled Sailing Interval in Days on the Average Cost Per Shipment
Figure 4-6 The Effect of the Scheduled Sailing Interval in Days on the Average Order Cycle Time
Experiment 6 (H\textsubscript{06})

Hypothesis 6 was designed to test the effect of increasing the shipping interval on the variance of the order cycle.

\textbf{H\textsubscript{06}} Increasing the maximum holding time for orders from one day to 4 days to 7 days will have no effect on the variance of the order cycle.

Increasing the sailing interval and thus the consolidation period significantly increases the variance of the order cycle according to the ANOVA data presented in Table 4-3. The effect is presented graphically in Figure 4-7. A comparison of the group means using Scheffe's technique revealed that all four are significantly different at the .01 level. Null hypothesis 6 is therefore rejected.

Experiments 7, 8, 9 (H\textsubscript{07}, H\textsubscript{08} and H\textsubscript{09})

Hypotheses 7, 8 and 9 were designed to test the effects of the use of stop-offs on average costs, average order cycle and order cycle variance.

\textbf{H\textsubscript{07}} The use of the stop-off privilege has no effect on the average cost per order.

\textbf{H\textsubscript{08}} The use of the stop-off privilege has no effect on the average order cycle length.

\textbf{H\textsubscript{09}} The use of the stop-off privilege has no effect on the variance of the order cycle.

Due to the deletion of the stop-off privilege from the research study, experiments 7, 8 and 9 were not conducted and thus hypotheses 7, 8 and 9 were not tested.
Figure 4-7  The Effect of the Scheduled Sailing Interval on the Order Cycle Variance
Experiments 10, 11 and 12 (H₀₁₀, H₀₁₁ and H₀₁₂)

Hypotheses 10, 11 and 12 were developed to test the interaction effects of the number of pool points and the length of holding time.

H₀₁₀ Increasing the number of pool points from zero to 10 to 30 to 50 to 70 and increasing the maximum holding time from 1 to 4 to 7 to 10 days produces no interaction effect on the average cost per order.

H₀₁₁ Increasing the number of pool points from zero to 10 to 30 to 50 to 70 and increasing the maximum holding time from 1 to 4 to 7 to 10 days produces no interaction effect on the average order cycle length.

H₀₁₂ Increasing the number of pool points from zero to 10 to 30 to 50 to 70 and increasing the maximum holding time from 1 to 4 to 7 to 10 days produces no interaction effects on the order cycle variance.

The interaction effect of the number of pools and the length of the scheduled shipping interval in days was found to be very significant for the average cost per order, the average order cycle and the variance of the order cycle. The analysis of variance results for each of the three measures are presented in Tables 4-1, 4-2 and 4-3 respectively.

Figure 4-8 depicts graphically the relationship of average order costs to the number of pool points and the length of the scheduled sailing interval. It can be seen in Figure 4-8 that average costs per order rise dramatically as the number of pool points increase for a consolidation system with only a one day or four day shipping interval while with the longer intervals of 7 and 10 days average costs rise only very little, if at all. Furthermore, only the systems with shipping intervals of 7 and 10 days result in average costs per order less than an LTL direct system.
Figure 4-8  The Effects of the Number of Pools and the Scheduled Sailing Interval on the Average Cost Per Order
The effect of the number of pool points and the length of the shipping interval on the average order cycle time is just the opposite from its effect on costs. As can be seen in Figure 4-9 the average order cycle time becomes progressively slower as the number of pool points and the length of the shipping interval increase.

As can be seen in Figure 4-10 the effect of the two factors is to increase the order cycle variance as the shipping interval lengthens.

Based on the results of the analysis of variance all three null hypotheses, \( H_0^{10}, H_0^{11} \) and \( H_0^{12} \) are rejected.

**Experiments 13, 14 and 15 (\( H_0^{13}, H_0^{14} \) and \( H_0^{15} \))**

Hypotheses 13, 14 and 15 were developed to test the interaction effects of increasing the number of pool points and the use of the stop-off privilege.

- \( H_0^{13} \) Increasing the number of pool points from zero to 10 to 30 to 50 to 70 and using the stop-off privilege results in no interaction effect on the average cost per order.

- \( H_0^{14} \) Increasing the number of pool points from zero to 10 to 30 to 50 to 70 and using the stop-off privilege results in no interaction effect on the length of the average order cycle.

- \( H_0^{15} \) Increasing the number of consolidation points from zero to 10 to 30 to 50 to 70 and using the stop-off privilege results in no interaction effect on the variance of the order cycle.

Due to the deletion of the stop-off privilege from the research study, experiments 13, 14 and 15 were not tested.
Figure 4-9  The Effect of the Number of Pool Points and the Scheduled Sailing Interval on the Average Order Cycle Time
Figure 4-10  Effect of the Number of Pool Points and the Shipping Interval on the Variance of the Order Cycle.
Experiments 16, 17 and 18 (H_{016}, H_{017} and H_{018})

Hypotheses sixteen through eighteen were designed to test for the two way interaction effects of increasing the maximum holding time and the use of the stop-off privilege.

H_{016} Increasing the maximum holding time from 1 to 4 to 7 to 10 days and the use of stop-offs produces no interaction effect on the average cost per order.

H_{017} Increasing the maximum holding time from 1 to 4 to 7 to 10 days and the use of stop-offs produces no interaction effect on the average length of the order cycle.

H_{018} Increasing the maximum holding time from 1 to 4 to 7 days and the use of stop-offs produces no interaction effect on the variance of the order cycle.

Due to the deletion of stop-offs from the research study, experiments 16, 17 and 18 were not conducted and thus hypotheses 16, 17 and 18 were not tested.

Experiments 19, 20 and 21 (H_{019}, H_{020} and H_{021})

Null hypotheses 19, 20 and 21 were designed to test the three way interaction effects on system performance of increasing the number of consolidation points, increasing the number of holding days and the use of stop-offs.

H_{019} Increasing the number of consolidation zones from zero to 10 to 30 to 50 to 70, increasing the maximum holding time and the use of stop-offs result in no interaction effect on average costs per order.

H_{020} Increasing the number of consolidation zones from zero to 10 to 30 to 50 to 70, increasing the maximum holding time and the use of stop-offs result in no interaction effect on average order cycle time.
Increasing the number of consolidation zones from zero to 10 to 30 to 50 to 70, increasing the maximum holding time and the use of stop-offs result in no interaction effect on the variance of the order cycle.

Due to the deletion of stop-offs from the research study, experiments 19, 20 and 21 were not conducted and therefore hypotheses 19, 20 and 21 were not tested.

Other Findings

Two factors not originally proposed to be included in this study were added. These two factors are shipment release strategies and the number of orders in the system. The two shipment release strategies which were included in the study were found to be used by several firms and are assumed to be relatively common in industry thus increasing the applicability of the study's findings.

Daily order receipts numbering 50 and 200 were added to increase the generalizability of the research at least to firms with order volumes between these two extremes.

The remainder of this section reports the findings of experiments of the main effects of these two additional factors and their two way interactions with the two original variables, number of pool points and shipping interval length, and with each other. Interactions greater than two, while found to be statistically significant using analysis of variance and presented in Tables 4-1, 4-2, and 4-3, on an order of magnitude are not consequential. Their significance is based more on the number of orders generated per replication and the number of replications per cell. There is also the problem of meaningfully interpreting the interaction affects of more than two variables.
Shipment Release Strategies

The two shipment release strategies tested were found to produce significant differences in the average cost per order, the average order cycle time and the variance of the order cycle. The F ratios and significance levels for each dependent variable can be found in Tables 4-1, 4-2 and 4-3 respectively. Table 4-4 presents the cell means for each strategy. It can be seen from Table 4-4 that the scheduled sailing strategy was $1.70 per order cheaper, 0.21 days slower and had greater variance.

Effect of the Number of Orders Entering the System Each Day

As can be seen in Tables 4-1, 4-2, and 4-3 the number of orders entering the system each day, either 50 or 200, significantly affected the average costs per order, the average order cycle time and the order cycle variance. All three measures were significantly higher for the cases where 50 orders per day entered the system. The specific numbers for each measure are presented and compared with an LTL direct system in Table 4-5. In Table 4-5 it can be seen that the LTL direct system is both faster and experiences a lower level of variance than either the 50 or 200 order per day consolidation system. It is also apparent that the 200 order per day system is more economical than the LTL direct system but the 50 order per day consolidation system is the most costly.
Table 4-4.

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Scheduled Sailing</th>
<th>Scheduled Sailing and Volume</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Cost Per Order</td>
<td>$145.68</td>
<td>$147.38</td>
<td>$-1.70 1.17%</td>
</tr>
<tr>
<td>Average Order Cycle Time (days)</td>
<td>9.02</td>
<td>8.81</td>
<td>.21 2.3%</td>
</tr>
<tr>
<td>Variance of the Order Cycle (days)</td>
<td>15.55</td>
<td>14.52</td>
<td>1.03 6.62%</td>
</tr>
</tbody>
</table>
Table 4-5.

The effects of the number of orders entering the system each day on the average cost per order, the average order cycle time and the variance of the order cycle.

<table>
<thead>
<tr>
<th></th>
<th>No Consolidation</th>
<th>Number of Orders 50</th>
<th>Number of Orders 200</th>
<th>Difference Between 50 and 200 Orders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Cost Per Order</td>
<td>$144.57</td>
<td>$153.47</td>
<td>$139.60</td>
<td>$13.87</td>
</tr>
<tr>
<td>Average Order Cycle (days)</td>
<td>8.09</td>
<td>9.52</td>
<td>8.32</td>
<td>1.2</td>
</tr>
<tr>
<td>Variance of Order Cycle (days)</td>
<td>10.34</td>
<td>16.98</td>
<td>13.10</td>
<td>3.88</td>
</tr>
</tbody>
</table>
Effect of the Number of Pool Points and the Number of Orders

The interaction of the number of pools and the number of orders received by the system daily was found to be very significant in terms of average costs per order, average order cycle time and the variance of the order cycle as presented in Tables 4-1, 4-2 and 4-3 respectively.

Figure 4-11 presents graphically the relationship between average costs per order and the number of pool points and orders per day. From this graph it can be seen that the larger number of orders results in much lower average costs per order for all numbers of pool points when compared to the 50 order per day curve. It is also evident that the larger number of orders substantially dampens the tendency for costs to rise as the lower volume, marginal pool points are added to the network. Only at the 70 pool point network does the average cost per order rise appreciably for the 200 order per day system. It must be concluded that the increase in average order costs as pool points are added, noted in the main effects analysis of the numbers of pool points, primarily is the result of the 50 order per day cases. It is also significant to note that all of the 50 order per day costs are higher than the LTL direct costs and that all of the 200 order per day costs are below the LTL direct costs.

The interaction effect of the number of pools and the number of orders entering the system daily on the average order cycle time is presented graphically in Figure 4-12. The average order cycle time for the system with 50 orders per day is 1.0 to 1.5 days longer than the system with 200 orders and it tends to lengthen somewhat with the
Figure 4-11  Effect of the Number of Pools and the Number of Orders on the Average Cost Per Order
Figure 4-12  The Effect of the Number of Pools and the Number of Orders on the Average Order Cycle Time
addition of pool points. Furthermore, the average order cycle time is shorter than LTL direct only for the 10 pool point system, in all other cases it is longer.

The interaction effect of the number of orders and the number of pool points on the variance of the order cycle is presented in Figure 4-13. The variance is higher for the 50 order per day system than for the 200 order per day system. The shapes of the 50 order and the 200 order curves are similar in that they both increase substantially from 10 to 30 pool points and then level off, declining slightly as they reach 70 pools.

**Effect of the Number of Pool Points and the Shipment Release Strategy**

The interaction effect of the number of pool points and the order release strategy was found not to be significant at the .05 level for the average cost per order and the variance of the order cycle. It was found to be significant for average order cycle time. The results of the analysis of variance are presented in Tables 4-1, 4-2 and 4-3.

As can be seen in Figure 4-14 the order release strategy of scheduled sailing and volume results in a somewhat faster transit time than scheduled sailing for all levels of pool points.

**The Effect of the Number of Orders Entering the System and the Order Release Strategy Used**

As can be seen in Tables 4-1, 4-2 and 4-3 the results of the analysis of variance indicate that the number of orders entering the system each day and the shipment release strategy employed interact to
Figure 4-13  The Effect of the Number of Pools and the Number of Orders on the Variance of the Order Cycle
Figure 4-14 Effect of the Number of Pools and Order Release Strategy on Average Order Cycle Times
significantly effect the average cost per order, the average order cycle time and the order cycle variance.

From the cell means presented in Table 4-6 (A) it can be seen that the average cost per order changes with the release strategy employed only for the system receiving 200 orders per day. The cost per order is not sensitive to the release strategy for the 50 order per day system.

The cell means presented in Table 4-6 (B) reveal the same relationship of average order cycle time to the number of orders and the release strategy employed as the average cost per order revealed. That is, the 50 order per day system is not sensitive to the strategy used while the 200 order per day system is sensitive to the strategy used.

Table 4-6 (C) reveals a similar relationship for order cycle variance but not nearly as pronounced as for the two dependent variables discussed above.

**Effect of the Number of Orders Entering the System and the Length of the Shipping Interval**

The results of the analysis of variance presented in Table 4-1 indicate that the interaction of the number of orders entering the system each day and the length of the scheduled shipping interval did not significantly effect the average cost per order. However, the analysis of variance results presented in Tables 4-2 and 4-3 indicate that the interaction of these two factors did significantly effect the average order cycle and the variance of the order cycle, respectively.
Table 4-6.

The effects of the Shipment Release Strategy Employed and the Number of Orders Entering the System Each Day on (A) the average cost per order, (B) the average order cycle time and (C) the order cycle variance.

<table>
<thead>
<tr>
<th>Release Strategy</th>
<th>Scheduled Sailing</th>
<th>Scheduled Sailing and Volume</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Effect on Average Cost Per Order</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 Orders per Day</td>
<td>$153.42</td>
<td>$153.51</td>
<td>.06</td>
</tr>
<tr>
<td>200 Orders per Day</td>
<td>$137.94</td>
<td>$141.25</td>
<td>2.40</td>
</tr>
<tr>
<td>(B) Effect on Average Order Cycle Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 Orders per Day</td>
<td>9.55</td>
<td>9.49</td>
<td>.62</td>
</tr>
<tr>
<td>200 Orders per Day</td>
<td>8.50</td>
<td>8.14</td>
<td>4.24</td>
</tr>
<tr>
<td>(C) Effect on Order Cycle Variance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 Orders per Day</td>
<td>17.36</td>
<td>16.60</td>
<td>4.38</td>
</tr>
<tr>
<td>200 Orders per Day</td>
<td>13.75</td>
<td>12.45</td>
<td>9.45</td>
</tr>
</tbody>
</table>
Figures 4-15 and 4-16 present the effect of the scheduled shipping interval and the number of orders on the average order cycle time and the variance of the order cycle respectively. From these two graphs it can be seen that both the average order cycle time and the variance of the order cycle rise much more rapidly for the system receiving 50 orders per day than for the 200 order per day system.

**Shipping Interval and Order Release Strategy**

Analysis of variance, the results of which are presented in Tables 4-1, 4-2 and 4-3 indicates that the shipment release strategy and the length of the scheduled shipping interval interacted significantly to effect the average cost per order, the average order cycle and the variance of the order cycle. It should be noted that based on the F-ratios the effect is much stronger for the average order cycle and the order cycle variance than for the average cost per order.

As can be seen in Figures 4-17, 4-18 and 4-19 the effect on all three dependent variables as the shipping interval is lengthened is for the performance of the two shipment release strategies to progressively diverge. In the case of the average costs per order the scheduled sailing strategy becomes somewhat cheaper while for the average order cycle and the variance of the order cycle the scheduled sailing strategy becomes progressively longer and more variable.
Figure 4-15 Effect of the Shipment Release Strategy and Orders Received per Day on the Average Order Cycle Time
Figure 4-16 Effect of the Shipment Release Strategy and Orders Received Per Day on the Variance of the Order Cycle.
Figure 4-17  Effect of Shipment Release Strategy and Scheduled Shipping Interval on the Average Cost Per Order
Figure 4-18: Effect of the Shipment Release Strategy and Scheduled Shipping Interval on the Average Length of the Order Cycle.
Average Order Cycle Length in Days

Figure 4-19 Effect of the Shipment Release Strategy and Scheduled Shipping Interval on the Average Length of the Order Cycle.
Other Findings Relative to the Number of Orders

Further analysis of the effects of the number of orders entering the system daily on the average cost per order was performed to determine the number of orders at which the firm would be indifferent to either an order consolidation system or an LTL direct system. For this analysis a linear relationship between the number of orders and the average cost per order was assumed to exist.

The indifference points were calculated using the equation below.

\[
\text{(7) Point of Indifference} = 200 - \left( \frac{\text{LTL} - A}{A - B} \right) \frac{150}{A - B}
\]

where

Point of Indifference = Number of orders which produces average costs per order equal to the average costs per order in an LTL direct system.

A = Average cost per order with 200 orders per day.

B = Average cost per order with 50 orders per day.

LTL = Average cost per order for an LTL Direct System

The calculation merely determines the slope of the cost curve and the number of orders needed to equal the LTL direct costs per order. The overall indifference point was calculated to be 147 orders per day and is presented graphically in Figure 4-20. Calculating the indifference points for systems with 1, 4, 7 and 10 day shipping intervals resulted respectively in indifference points of 281, 151, 87 and 49 orders entering the system daily. The graph in Figure 4-21
Figure 4-20 The Effect of the Number of Orders Entering the System Daily on the Average Cost Per Order
Figure 4-21 The Number of Orders Entering the Consolidation System Daily Which Produce Average Costs Per Order Equal to an LTL Direct Distribution System
<table>
<thead>
<tr>
<th>Scheduled Shipping Interval</th>
<th>Number of Orders Received</th>
<th>LTL Direct Strategy</th>
<th>10 Pools</th>
<th>30 Pools</th>
<th>50 Pools</th>
<th>70 Pools</th>
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</thead>
<tbody>
<tr>
<td>1 Day</td>
<td>50</td>
<td>144.64</td>
<td>153.08</td>
<td>155.15</td>
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<tr>
<td>4 Days</td>
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<td>145.06</td>
<td>146.50</td>
<td>145.28</td>
<td>152.09</td>
<td>155.05</td>
</tr>
<tr>
<td></td>
<td>200</td>
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<td>136.50</td>
<td>138.75</td>
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</tr>
<tr>
<td>7 Days</td>
<td>50</td>
<td>143.22</td>
<td>142.83</td>
<td>141.12</td>
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<td>149.08</td>
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<tr>
<td></td>
<td>200</td>
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<td>134.63</td>
<td>137.55</td>
<td>131.07</td>
<td>134.39</td>
</tr>
<tr>
<td>10 Days</td>
<td>50</td>
<td>143.28</td>
<td>140.32</td>
<td>136.75</td>
<td>144.76</td>
<td>150.61</td>
</tr>
<tr>
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<td>134.36</td>
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Figure 4-22 Revised Experimental Design Showing Cell Means of Average Order Costs Obtained From Experiments
<table>
<thead>
<tr>
<th>Scheduled Shipping Interval</th>
<th>Number of Orders Received</th>
<th>LTL Direct Strategy</th>
<th>10 Pools</th>
<th>30 Pools</th>
<th>50 Pools</th>
<th>70 Pools</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Day</td>
<td>50</td>
<td>8.09</td>
<td>8.36</td>
<td>8.37</td>
<td>8.64</td>
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<td>8.04</td>
<td>8.84</td>
<td>8.69</td>
<td>10.66</td>
<td>10.57</td>
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<td>8.54</td>
<td>7.46</td>
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</tbody>
</table>

Figure 4-23: Revised Experimental Design Showing Cell Means of Average Order Cycle Time Obtained From Experiments
<table>
<thead>
<tr>
<th>Scheduled Shipping Interval</th>
<th>Number of Orders Received</th>
<th>LTL Direct Strategy</th>
<th>10 Pools</th>
<th>30 Pools</th>
<th>50 Pools</th>
<th>70 Pools</th>
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</thead>
<tbody>
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<td>11.71</td>
<td>11.59</td>
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</tr>
<tr>
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<td>11.12</td>
<td>11.01</td>
<td>11.96</td>
<td>11.57</td>
</tr>
<tr>
<td>7 Days</td>
<td>50</td>
<td>10.35</td>
<td>16.66</td>
<td>16.60</td>
<td>20.48</td>
<td>19.53</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>10.45</td>
<td>11.46</td>
<td>9.78</td>
<td>15.07</td>
<td>13.98</td>
</tr>
</tbody>
</table>

*Figure 4-24 Revised Experimental Design Showing Cell Means of Order Cycle Variance Obtained From Experiments*
presents these findings. Thus, as the number of holding days increases the number of orders entering the system daily needed to produce an economically viable consolidation system decreases.

Summary

The objective of this chapter has been to present the findings of the experiments concerning the effects of the number of pool points, the length of the shipping interval, the number of orders entering the system each day and the shipment release strategy employed on the average cost per order, the length of the average order cycle and the variance of the order cycle. Hypotheses H₀₁ through H₀₆ and H₀₁₀ through H₀₁₂ were rejected. Hypotheses 7 through 9 and 13 through 21 were not tested because of the decision not to test the effect of the stop-off privilege. It was also found that the shipment release strategy employed was somewhat important and that the number of orders in the system was very important. Furthermore, it was found that most of the two way interaction effects of the four factors were significant beyond the .05 level.
V. SUMMARY AND CONCLUSIONS

This chapter will present a comprehensive discussion of the research study. The first section restates the problem, purpose and methodology of the study and summarizes its findings. The second section presents the conclusions of the study, based on findings from the research hypotheses and other sources. The third section reviews the methodological, managerial and societal implications of the study. The fourth section contains suggestions for further research.

A Brief Statement of the Problem

Most business firms, especially those marketing packaged consumer goods, are faced with the problem of shipping small, less than truckload (LTL) orders. These orders are increasingly a problem as transportation costs, particularly for small shipments, continue to escalate and as transportation service continues to deteriorate for small shipments. Thus, shippers face increasing pressure to ship in larger quantities. Business firms also feel the pressure to order in smaller quantities primarily to reduce their inventory investment.

Business firms which ship in small quantities are therefore faced with escalating transportation costs and deteriorating service while at the same time customers are ordering in increasingly smaller quantities.
There are three basic distribution strategies a shipper might employ to handle small shipments: 1) LTL direct, 2) field warehousing and 3) order consolidation. Order consolidation compared to field warehousing has the advantage of a lower investment in inventory and facilities and requires fewer people to operate it. Compared to LTL direct, order consolidation offers the potential for lower transportation costs and better transportation service. Thus, order consolidation offers the shipper advantages over LTL direct and field warehousing. The primary disadvantage of order consolidation is that the order cycle may be lengthened unacceptably as orders are held to accumulate truck-load shipments.

The challenge in designing an order consolidation or pool system is to capitalize on the advantages it offers without damaging the customer service level by increasing the variability and length of the order cycle.

There are several major decision areas in the design of an order consolidation system. Four of these are: 1) choosing the number and location of pool points to be included in the system, 2) establishing the maximum number of days orders can be held to achieve consolidation, 3) whether or not to use stop-offs to partially unload which allow a shipper to consolidate shipments to separate geographic points enroute to the destination, and 4) which of several shipment release strategies should be used such as establishing a fixed shipping schedule or releasing a shipment when a predetermined volume is collected or some
combination of these techniques. These decision areas are all important because they will affect the transportation costs of the system as well as the order cycle length and variability. They are also interrelated. For example, if relatively low volume pool points are added to the system it may be necessary to increase the length of the order accumulation period in order to accumulate a truckload consolidated shipment and thereby reduce transportation costs.

It is also important to note that a search of the literature revealed that the problem of order consolidation has been approached only on a limited basis and as a result there are few principles or methodologies available in the public domain to assist in the design of an order consolidation system.

**Purpose of the Study**

It is the purpose of this research to develop a reliable, flexible and practical methodology for analyzing an order consolidation system and demonstrate its use by investigating several major decision areas and relationships within an order consolidation system. More specifically, the purpose of the study is:

1. To develop a computer based simulation model of a distribution system for a firm shipping a nonseasonal, packaged consumer product nationally from a single origin.

2. To utilize the validated simulation model to investigate the response of the distribution system in terms of average costs per order, average order cycle time and the variance of the
order cycle to changes in:

a) the number of consolidation points in the network
b) the maximum holding time allowed to achieve consolidation
c) the shipment release strategy employed
d) the volume of orders received by the system

Originally, the study did not include investigations of the effects on different shipment release strategies or of the volume of orders entering the system. During the conduct of the research it became evident that the logic used to release orders had been neglected. Several release strategies were identified and two variations of one, referred to as scheduled sailing, were selected for the study. With scheduled sailing shipping dates are established at regular intervals. On a shipping date all orders are released after an attempt is made to consolidate as many orders as possible. This technique has the advantage of ease of operation and consistent service. Customers, knowing the schedule, can accurately anticipate deliveries.

A variation of the scheduled sailing logic is to retain the schedule but release pool shipments anytime they achieve a specific size. This technique has the advantage of speeding up service somewhat but perhaps increasing its variability.

A major change in the purpose of the study was the deletion of stop-offs to unload. As the study progressed from its early phases to actual implementation, several problems concerning stop-offs became evident.
First, data limitations required that the U.S. market be aggregated into 399 cities. While this is a relatively low level of aggregation by most standards, it was found to be too great to accurately depict stop-off possibilities. Since the stop-off points are charged the freight rate to the final destination, the most economically attractive stop-offs are those closest to the final destination. But at an aggregation level of 399 the closest points are all included in the final destination. For example, a stop-off at Gary, Indiana, with a final destination at Chicago might be a good possibility. However, Gary is included in Chicago and therefore that possibility could not be modeled. The closest city to Chicago, in this example, which could receive a stop-off is South Bend, Indiana, but it is too far from Chicago to be economical. Therefore, the level of aggregation does not allow an accurate representation of the stop-off problem.

It also became evident that the stop-off logic was relatively complex and that as the numbers of possible destinations and stop-offs increased the problem became a relatively large combinatorial problem. Each potential stop-off must be tested in combination with all other possible stop-off and destination points in terms of costs, since the objective of the stop-off is to reduce costs, and also in terms of mileage because the distance from the plant to the final destination cannot be increased by more than a certain percentage by the stop-off without incurring an economic penalty. While difficult to model, the stop-off logic would also increase substantially the number of computations and the file searches which must be performed by the model.
which would increase the operating expenses of an already expensive model to operate.

Stop-offs are also believed to be a highly opportunistic cost reduction technique which is probably used most often on an ad hoc basis, involving relatively few orders and not affecting the basic structure of the consolidation system. Thus, the absence of stop-offs from the model is not felt to be a major detraction from it which would nullify the results.

Therefore, the decision was made to drop stop-offs from the study on the basis that due to data limitations they could not realistically be modeled and even if they could, they would increase the costs of the research beyond the benefits to be derived from it. Furthermore, their deletion does not seriously flaw the model nor the findings obtained from it.

**Scope of the Study**

The study is limited to a packaged goods firm with national distribution, nonseasonal demand, a predetermined order size distribution and a constant number of orders received daily. The distribution of orders by weight is based on the actual order stream of a medium sized packaged goods manufacturer. The average order size is approximately 1300 pounds. Furthermore, there is only one plant, product is not stored at any other locations, and the firm is assumed to ship only one product.
Research Methodology

The research methodology used in this study is experimentation using a computer based simulation model. This methodology was chosen because the data requirements are too great for a manual technique and the stochastic nature of the problem could not be represented with a deterministic technique such as linear programming.

The simulated network consists of one plant or origin, 70 possible pool points and 399 markets. Each market was assigned on the basis of least cost to either a pool point or the plant for shipment. If the market was assigned to the plant each order destined for it would not be consolidated but would be shipped on an LTL basis direct from the plant to the market.

The basic operation of the model is described below. First, the necessary data and system parameters such as the number of pool points, the market assignments to pool points, the mileage table, the number of orders to be generated each day, and the length of the scheduled shipping interval are fed into the model.

Next, orders are generated for the day and their weights and origins are determined probabilistically. They are then put into the active order file with their pool points attached. Next, the active order file is searched for orders to be shipped. Any order which is shipped must have its transit time and arrival date determined and its freight cost calculated. Unconsolidated orders are shipped LTL direct the day they are received. Lastly, each day the active order file is searched for
orders arriving that day. Arriving orders are deleted from the active order file and transferred to the output file.

Once the model was coded and running on the computer, it was validated by tracing a few orders through it and checking their progress at key points to determine if the model was operating properly. Next, the model was run full scale and the results checked for reasonableness.

The experimental design is a four factor, full factorial design. The four factors and their levels are as follows:

1. Number of consolidation points
   a) 0 or LTL direct
   b) 10 pool points
   c) 30 pool points
   d) 50 pool points
   e) 70 pool points

2. Number of orders entering the system each day
   a) 50 orders
   b) 200 orders

3. Order Release Strategies
   a) Scheduled sailing
   b) Scheduled sailing and volume

4. Maximum holding time or more precisely the interval in days between scheduled shipping days
   a) one day
   b) 4 days
   c) 7 days
   d) 10 days

The number of orders entering the system each day was determined by choosing two quantities which would cover a wide range of packaged consumer goods manufacturers. Assuming 250 operating days per year, 50 orders per day amounts to 12,500 orders annually and with an average
order size of 1300 pounds the annual weight shipped equals 16.25 million pounds. It was felt that these numbers would represent many small to medium sized firms. On the other hand, 200 orders per day results in 50,000 orders and 65 million pounds of product per year. Such volumes would be typical of many relatively large sized firms, although it is recognized that the very largest firms would exceed these volumes. In general, it was felt that a very large proportion of firms shipping packaged consumer goods in the U.S. which might be interested in order consolidation would fall within the 50 to 200 order per day range. Furthermore, even if a particular firm did not fall within this range, many of the results can still be extended to it.

The three dependent variables are the average cost per order, the average order cycle length and the variance of the order cycle.

Once the experiments were run, analysis of variance (ANOVA) was used to determine the significance of each of the factors and their two way interactions. If the factor was found to be significant, i.e. beyond the .05 level, Scheffe's multiple comparison technique was used to determine significant differences between the cell means for each factor and thus provide insight into the direction of the effect.

Conclusions Relative to the Research Hypotheses

The results of the experiments testing the null hypotheses proposed in Chapter I are presented below.
Effects of the Number of Pool Points on Costs

In this first experiment, hypothesis 1 specifically examined the effect of the number of pool points on the average costs per order. The number of pool points varied from zero or LTL direct to 10, to 30 to 50 and 70. It was found that increasing the number of pools significantly (at the .001 level) raised the average costs per order. In fact, only the 10 pool point system was less costly than the LTL direct system. Hypothesis 1 was rejected. The underlying cause of the increase in average costs per order is the number of orders entering the system daily and the number of days orders can be held. The 50 order per day system and the shorter holding times caused the overall costs to be increased.

Average costs per order rise as pool points are added because the points with the greatest volumes and highest potential savings are used first. Those that are added are lower volume and offer lower potential savings from consolidation. This is particularly critical for a system experiencing a relatively low volume of orders.

A consolidated shipment without sufficient weight will be more expensive than shipping LTL because the consolidation savings from the plant to the pool movement will not be sufficient to cover the LTL beyond costs for the individual orders. Thus, costs in a low order volume system with short shipping intervals could be expected to rise as pool points are added.
The savings gained from consolidation are generally greatest for the smaller shipments due to the structure of freight rates. For any pool point-destination combination the order size at which savings occur from consolidation may be relatively heavy or light. As the more marginal points are added to the system the weight per order necessary to produce savings decreases and the mix of orders in the shipment may overall produce a cost greater than no consolidation (LTL direct). Thus, pool points may be added which, given the distribution of order weights, may actually increase overall costs.

One other factor which partially accounts for the increasing average order costs with the addition of pool points is the fact that as pool points are added they begin to crowd each other and impinge upon their service areas thus decreasing the volume through nearby pools. The addition of new pools may divert orders previously moving through pools with volumes adequate to secure savings. Once the new pools are in place, volumes to the previously established pools may not be sufficient to achieve an equal level of savings. Again, a low volume system with a short shipping interval would be much more susceptible to such a phenomenon than a high volume system.

The Effect of the Number of Pools in the Average Order Cycle Length

The second experiment examined the effect of the number of pool points on the average order cycle time. It was found that as the number of pool points increased so too did the average order cycle time from 8.09 days for LTL direct to 9.3 days for the 70 pool systems. This factor was found through analysis of variance to be significant at the .001 level.
Thus, null hypothesis 2 was rejected.

The effect of the number of pools on average order cycle time can, as with costs, be related to the volume of orders moving through individual pool points. A low volume pool point which fails to generate truckload size shipments will experience LTL transit times plus the handling time at the pool point and the delivery time from the pool point to the final destination. As lower volume points are added to the network, overall transit times can be expected to increase.

**Effect of the Number of Pool Points on the Variance of the Order Cycle**

Experiment 3 investigated the effect of the number of pool points on the variance of the order cycle and it was found through ANOVA that this factor was significant at the .001 level. Null hypothesis 3 was therefore rejected. The variance of the order cycle is higher than LTL direct for all consolidation cases regardless of the number of pool points. Order cycle variance for the consolidation system rises from 10 to 30 pools, levels off at 50 pool points and declines slightly at 70 pool points. Scheffe's multiple comparison technique confirmed this pattern when it divided the cell means for each of the factor levels into 3 significant groups at the .01 level. These groups are: 1) 10 pools, 2) 30, 50 and 70 pools and 3) 10 and 70 pools.

The order cycle variance can be expected to be higher for a consolidation system than for an LTL direct system because orders will be held for consolidation while all other orders will be released the day received. The consolidated orders will average longer order cycles than the LTL direct orders not included in the consolidation network thereby
increasing the variance. As more pool points are added more orders are included in the consolidation system thus increasing the overall average order cycle, pulling the average closer to the consolidated orders thus reducing the variance.

The Effect of Varying the Scheduled Sailing Interval (Maximum Holding Time) on Average Order Costs

Increasing the length of time orders are held to achieve consolidation was found, using ANOVA, to significantly decrease the average costs per order. Average order costs dropped from $160.18 at one day holding time to $138.07 per order for 10 days for a decrease of almost 14%. Scheffe's multiple comparison technique confirmed the direction of this decrease when at .01 level three significant subsets of the cell means for the factor levels were found. These subsets are 1) one day, 2) four and 7 days and 3) 10 days.

The longer the period that orders can be held the greater the probability that consolidation will be possible and the larger will be the shipments to individual pool points. Large shipments lead to lower transportation costs.

Effect of Varying the Scheduled Sailing Interval (Maximum Holding Time) on Average Order Cycle Time

It was found using ANOVA that increasing the scheduled sailing interval tended to significantly (.001 level) increase the average order cycle time therefore null hypothesis 5 was rejected. At the one day interval average order cycle time was 8.5 days. As many of the orders in the system are held at the plant for longer and longer periods of time it
is only natural that the average order cycle time would increase. The fact that it does not increase more than .9 days can be attributed to the fact that the orders not assigned to a pool point are shipped LTL direct at the end of the day on which they were received regardless of the pool system's scheduled sailing date.

Effect of Varying the Scheduled Sailing Interval (Maximum Holding Time) on Order Cycle Variance

Increasing the shipping interval was found to significantly increase the order cycle variance. The ANOVA indicated significance at the .001 level therefore null hypothesis 6 was rejected. Scheffe's multiple comparison technique indicated that at the .01 level all four shipping intervals were significantly different.

Effect of Stop-offs on System Performance

Stop-offs were dropped from the study and therefore null hypotheses 7, 8, and 9 were not tested.

The Effect of the Number of Pool Points and the Length of the Scheduled Shipping Interval on System Performance

The interaction effect of the number of pools and the length of the scheduled shipping interval in days was found, using ANOVA, to be significant at the .001 level for the average cost per order, the average order cycle time and the variance of the order cycle. Null hypotheses 10, 11, and 12 were therefore rejected.

Average costs per order rise dramatically as the number of pool points increase for a consolidation system with only a one day or four
day shipping interval while with the longer intervals of 7 and 10 days average costs rise only very little, if at all. Furthermore, only the systems with shipping intervals of 7 and 10 days produced average costs per order less than an LTL direct system. The longer orders are held, the less likely average costs are to rise as the number of pool points increases. The longer intervals make possible heavier pool shipments thus reducing transportation costs.

In terms of order cycle length and order cycle variance the order cycle becomes progressively slower and more variable as the shipping interval is lengthened. The change in length and variability of the order cycle from 10 to 30 and more pool points is much larger for the 10 day interval than it is for the one day system. Increasing the number of pools has a much greater impact on the system with a 10 day shipping interval than on a system with a shipping interval of one day.

**Effects of Stop-offs Interacting with the Number of Pool Points and the Maximum Holding Time**

As discussed earlier, a decision was made not to include stop-offs in the study. Therefore null hypotheses 13 through 21 dealing with the interaction effects of stop-offs with the number of pool points and the maximum holding time were not tested.

**Conclusions Relative To Other Findings**

As explained earlier in this chapter, two independent variables were added to the research design. Null hypotheses were not proposed for these two factors and they are therefore discussed as other findings.
The one factor added consists of two variations of the scheduled sailing order release strategy. One involves holding all orders which might be consolidated for the entire interval and the other involves holding pool shipments until time runs out or a truckload shipment is formed, whichever comes first. They are referred to as scheduled sailing and scheduled sailing and volume respectively. The second factor added, number of orders, also includes two levels. They are 50 orders per day and 200 orders per day received by the system. Only the main effects and two way interactions are reported since, although the higher level interactions were found to be statistically significant, their significance is based on a large sample size.

**Effect of Shipment Release Strategies on System Performance**

Both of the shipment release strategies tested were found, using ANOVA, to produce statistically significant differences in the average cost per order, the average order cycle time and the variance of the order cycle. The scheduled sailing strategy was $1.70 per order cheaper, .21 days slower and had a variance 1.03 days greater than the scheduled sailing and volume strategy. The percentage differences for the two strategies on the three dependent variables were 1.2%, 2.3% and 6.62% respectively.

The results obtained are based on the fact that the scheduled sailing and volume strategy releases the orders that have been consolidated into truckload shipments, truckload being 24,000 lbs. in this case, earlier than the scheduled sailing strategy thus speeding up the order cycle. The scheduled sailing strategy is somewhat cheaper
because it continues to increase the size of the consolidated shipment for the entire interval. The scheduled sailing and volume strategy by leaving early may strand some orders which cannot be consolidated thus raising the costs of such a strategy. Also, the scheduled sailing shipments may be heavier and therefore cheaper. The scheduled sailing and volume strategy is somewhat less variable because shipments are being shipped sooner and therefore closer to the average time for all orders in the system.

Effect of the Number of Orders Entering the System Each Day

The number of orders entering the system daily was found, through ANOVA, to significantly affect the average cost per order, the average order cycle length, and the order cycle variance. All three performance measures were significantly higher for the 50 order system. Costs were $13.87 per order more expensive, the order cycle was 1.2 days longer, and the order cycle variance was 3.88 days higher for the 50 order system than for the 200 order per day system. Moreover, only the 200 order per day system experienced lower costs than the LTL direct system. The larger volume of orders and therefore shipping weight allows the potential of order consolidation to be realized. The low volume system cannot realize the potential and even suffers a penalty due to uneconomic shipments. The higher volume also speeds up the order cycle and reduces its variability because the larger shipments experience shorter transit times.
Effect of the Number of Pool Points and the Number of Orders

Using ANOVA it was determined that the interaction effects of the number of pool points and the number of orders entering the system daily was very significant in terms of average costs per order, average order cycle time, and order cycle variance. The 200 order per day system experiences much lower costs for a level of pool points than does the 50 order per day system. It was also found that the larger number of orders significantly dampened the tendency for costs to rise as the number of pool points increased. Average costs per order remained relatively constant at 10, 30 and 50 pool points and then rose somewhat at 70 points for the 200 order per day system. The average costs per order for the 50 order per day system rise each time the number of pool points increases. Furthermore, only the 200 order per day system is cheaper for all levels of pool points.

In terms of the effect on the order cycle, the average order cycle and the variability of it are lower for the higher volume system.

Again, the larger volume system makes possible speedier order cycles and larger, more economical consolidated shipments.

Effect of the Number of Pool Points and the Shipment Release Strategy

The interaction effect of the number of pool points and the order release strategy was found not to be statistically significant at the .05 level for the average cost per order and the variance of the order cycle. It was found to be significant for average order cycle time. The order release strategy of scheduled sailing and volume resulted in
a slightly faster transit time than scheduled sailing only for all
levels of pool points.

**Effect of the Number of Orders Entering the System and the Order
Release Strategy Used**

Using ANOVA, it was found that the interaction effect of the number
of orders entering the system each day and the order release strategy used
is significant in terms of the average cost per order, the average order
cycle time and the variance of the order cycle.

The basic relationship for all three performance measures is that at
50 orders per day, there is very little difference between the effects of
the order release strategy. However, at 200 orders per day, the
scheduled sailing release strategy produces less expensive, faster and
more variable results. The 50 order system is not sensitive to shipment
release strategies but the 200 order system is. The 50 order system does
not have enough volume to release orders early. It therefore makes low
volume, uneconomical consolidated shipments only on the scheduled sailing
day. The lower volume shipments also experience slower transit times
thereby increasing the order cycle length and variability. At 200 orders
per day, the system has sufficient volume to release some consolidated
shipments early.

**Effect of the Number of Orders Entering the System and the Length of the
Shipping Interval**

The results of the ANOVA indicate that the interaction of the number
of orders in the system and the length of the shipping interval is
significant only in terms of the length and variability of the order cycle.
Both the average order cycle and the variance of the order cycle rise much more rapidly for the 50 order system than for the 200 order per day system.

For the 50 order system, order cycle time increases each time the shipping interval is lengthened because few consolidated shipments have achieved the volume to be released early or to achieve truckload transit times. On the other hand, the 200 order per day system becomes somewhat faster (.28 days) as the interval is lengthened from one to four days and increases somewhat at 7 and 10 days. The decrease in order cycle time comes about as more orders are consolidated at four days than at one day, some are released early and the larger shipments reap shorter transit times. Order cycle time increases somewhat as the length of the shipping interval increases and orders in the system are held for successively longer periods of time.

**Effect of Shipment Release Strategy and the Length of the Shipping Interval**

ANOVA was used to determine that the interaction effect of the shipment release strategy and the length of the shipping interval is significant for the average cost per shipment, the average order cycle length and the order cycle variance. The effect on all three dependent variables as the length of the shipping interval increases is for the performance of the two shipment release strategies to progressively diverge. In the case of the average costs per order, the scheduled sailing strategy becomes somewhat cheaper because it is releasing heavier consolidated loads, while for average order cycle time and the variance of the order
cycle, the scheduled sailing strategy becomes progressively longer and more variable because orders are being released only at the end of the interval.

Further Analysis of the Effects of the Volume of Orders on Costs

Earlier in the analysis it was found that the average cost per order was much higher for a 50 order per day system than for a 200 order per day system. This relationship was assumed to be linear and the number of orders which produced costs equal to an LTL direct system were calculated. These indifference points were calculated for the overall data and for each level of the shipping interval. The overall number of orders at which a firm would be indifferent as to whether an order consolidation system or an LTL direct system was employed was 147 orders per day. The indifference points for a consolidation system with a 1, 4, 7 and 10 day shipping interval, respectively, were calculated to be 281, 151, 87 and 49 orders per day.

Implications of the Research

The evidence presented in this study has several methodological, managerial and societal implications which are discussed below.

Methodological Implications

Perhaps the greatest contribution of the study in terms of methodology is the fact that it demonstrates that a computer based simulation model can be effectively used to study the order consolidation problem.
It successfully integrated the cost and temporal aspects of the consolidation problem and it is unlikely that any other technique currently available could be employed as effectively and practically as computer based simulation.

Managerial Implications

A major finding of the study was the sensitivity of order consolidation to the volume of orders entering the system. To the manager, the volume of orders will to a large extent determine the number of pool points, the shipping interval or holding time and the shipment release strategy which must be used in order for the consolidation system to be viable in terms of economy and customer service.

It was also found that the holding time is very important in shaping the consolidation system since increasing holding time decreased costs in all cases. Furthermore, it was found that a manager can compensate for a low volume of orders by increasing the holding time. For the firm modeled in this study the number of orders needed for an economically viable consolidation system declined from 281 orders daily with a one day holding time down to 49 orders per day with a ten day holding time. The penalty for increasing the holding time is increased order cycle length and variability.

In order for the manager to intelligently make the decision concerning the length of the holding time, the length of the order
cycle and its variability which is acceptable to the target market must be known. In other words, market based customer service standards are an integral part of a consolidation system.

The implications of this study for the number of pool points will be discussed in terms of high and low order volume.

For the manager of the low order volume system the holding time must be relatively long and only the highest volume and most distant pool points should be consolidated to if the system is to be economically viable. While the effect on the overall variance and order cycle time is minor the effect on individual customers may be severe. If customer reaction to the lengthy holding time is significant the firm's alternatives are to ship LTL direct or to use a consolidation agent of some sort.

The manager of the high order volume system has much more discretion than the manager of the low order volume system but he too must know the customer service levels needed by his target market. The high volume manager can add pool points which will, up to a point, decrease transportation costs. He can add more points and further decrease costs by increasing the holding time. Moderate holding times may actually serve to decrease order cycle times compared to LTL direct because the resulting truckload shipments experience faster transit times than the LTL shipments. In such cases the decrease in transit times is greater than the holding time, however variability may be increased. Thus, a consolidation system can be designed which results in cost savings and time savings if volume is sufficient.
The manager is offered a clear choice between shipment release strategies. Scheduled sailing was found to be cheapest but it also produced longer and more variable order cycles. These effects can be moderated somewhat by adjusting the volume at which shipments are released in the scheduled sailing and volume strategy. Raising it from the study's 24,000 pounds would serve to decrease costs and increase order cycle times while lowering it would have the opposite effects.

**Societal Implications**

The implications of this study for society center on its methodological and managerial contributions. To the extent that business firms are better able to analyze, design and manage their distribution systems, society will benefit from a more efficient use and allocation of scarce resources. The primary benefit to society would come from a reduction in the use of scarce fuel supplies by decreasing short, fuel intensive, pick up and delivery trips and by increasing the utilization of vehicle capacity. Decreasing the use of fuel in distribution will help to reduce imports of oil from abroad thus improving the U.S. balance of payments and lessening global political pressures tied to oil consumption. More efficient use of petroleum products will also reduce the cost of distribution which can be passed on to consumers in the form of lower prices.
Suggestions for Further Research

A number of logical extensions of this research are discussed below:

1. In the study reported here, only two order release strategies are investigated. Others, such as releasing only on the basis of volume should also be investigated and compared with scheduled sailing. It is possible that even stronger relationships with order volume will be found.

2. The effects on the consolidation system of various levels of emergency orders and orders requesting specific shipping dates should also be studied. Such orders were not considered in this study.

3. Order consolidation in this study was compared to shipping orders LTL direct. The other major small shipment strategy, field warehousing should also be compared to order consolidation under various conditions with the objective of determining how each performs under certain scenarios.

4. In this study only one, nonseasonal distribution of order weights was used to generate orders. A logical extension of this study would be to test other order weight distributions to learn how they affect order consolidation system performance. Such changes as introducing seasonality and higher and lower average order sizes would help to further clarify the effects of consolidation on distribution system performance.

5. This study modeled a system with only one plant origin. Multiple origins should also be investigated. Certainly there are many companies with multiple shipping locations. An investigation of multiple shipping points would most likely look carefully at the use of mixing points also, where products from several sources would be processed for consolidation.

6. This study and its methodology provoke and make possible the investigation of the implementation of a minimum order quantity by a shipper. An order consolidation system may reduce some of the pressure on a firm for such a policy.

7. This study used only the order consolidation or the LTL direct strategy for each market. A mixed strategy for each market based perhaps on the weight of the order should be investigated and it should include field warehousing. A mixed distribution strategy such as this might be very effective under certain conditions.
8. The system in this study was assumed to have only one product. It would be more realistic to have a mix of products with varying densities and dimensions and perhaps incompatibilities.

9. The problem of inbound consolidation should also be approached. While conceptually just the mirror image of outbound consolidation as studied here, there are practical differences which should be investigated.

10. Current consolidation practices should be surveyed to point the way to further research and to help sharpen representations of order consolidation systems. For example, what are some of the shipment release strategies most often used, how common is order consolidation in industry, and how are pool points selected?

11. Further research should be conducted into ways of establishing systems of pool points. For example, can feasible networks be constructed using least cost, greatest savings, shortest distance or perhaps population? Techniques for generating pool point systems using these criteria should also be investigated.

12. This study assumed demand to be geographically dispersed in direct proportion to population. A study should be done to determine the validity of such an assumption.

13. This study used the overall average order cycle and variance as measures of the effects of order consolidation on customer service. While these overall measures are useful to some extent, a more detailed investigation of these effects is needed. The length and variance of the order cycle for consolidated and unconsolidated orders would provide greater insight into the effects of order consolidation. A further breakdown by market area or even individual markets would provide even greater insight into the problem. The range of order cycle times should also be captured.

14. Further research should be conducted to investigate the administrative costs involved in order consolidation to clarify the trade offs with alternative strategies.
APPENDIX A

GLOSSARY OF
ORDER CONSOLIDATION TERMS
GLOSSARY OF
ORDER CONSOLIDATION TERMS

ACR - All-Commodity Rates

Aggregate Tender - See Multiple Shipment Tender

All-Commodity Rates - See Freight, All Kinds

All-Freight Rates - See Freight, All Kinds

Assembly Point - See Consolidation Point

Beyond Rates - Sometimes used to refer to the transportation costs of the movement of orders to individual consignees from the break-bulk point. These costs can be either a local cartage charge at the line-haul destination or an LTL charge to a further destination.

Bill of Lading - Shipment documentation which serves as a shipper's receipt for the goods and a contract between the shipper and the carrier for the transportation of the shipment.

Break-Bulk Point - Where a consolidated shipment is broken up into smaller shipments for delivery to the individual consignees. May also be referred to as a "Pool Point" or "Distribution Point."

Class Rate - A point-to-point or mileage rate based on a commodity's transportation characteristics and the distance to be traveled. Class rates are related to each other as the class rate number is a percentage of the base class, typically 100. Class rates apply only in the absence of commodity rates. (See Flood, pp. 138-144.)

Commercial Zone - The area designated by the ICC around cities in which transportation wholly within it is exempt from economic regulation. The commercial zone includes a community, contiguous communities, and the area commercially a part of such communities.

Commodity Rate - There are three general types of commodity rates:
1. Those which are expressed as a percent of Class 1 or 100 and are called "commodity column rates."
2. Those which are specific rates applying on a specific commodity or related commodities between specific points
and sometimes by specific routes. Such rates are not constructed upon any systematic basis but are adjustments to meet the needs of particular shippers, localities or competitive conditions. All-commodity rates, all freight rates, all kinds rates are of this type.

3. Rates which are constructed on a systematic basis other than the class rate system such as on mileage or distance. (Taff, pp. 225-226 and Flood, pp. 150-153.

**Consolidation** - See Order Consolidation

**Consolidation Point** - Where orders are consolidated.

**Consolidator** - A shipper's agent who provides an order consolidation service for shippers under an agreement or contract.

**Deficit Weight** - The term used to refer to the difference in weight between the minimum weight and the actual weight of the shipment when the actual weight is less than the minimum weight. (See Flood, p. 221.)

**Distribution Point** - See Break-bulk Point

**Distribution Rates** - These rates cover the distribution of a consolidated shipment within a terminal area by the carrier who performs the line-haul service. The shipper must specify that service is requested and supply a separate bill of lading for each individual shipment in the vehicle which is consigned to an individual consignee at destination. If distribution rates are not available the shipper would consign the consolidated shipment to pool car or pool truck distributor. (See Flood, p. 173.)

**Distributor** - See Pool Car or Pool Truck Distributor

**FAK** - Freight, All Kinds

**Freight, All Kinds** - Commodity rates applicable on mixed freight. (See Flood, pp. 151-153.)

**Freight Consolidation** - See Order Consolidation

**Freight Forwarders** - An economically regulated agent who owns no line-haul equipment himself but accepts small shipments, consolidates them into larger shipments and then ships them by common carrier deriving his income from the difference between the rates charged the shipper (lower than the rate on his individual LTL or LCL shipment) and the rates charged the
forwarder for the movement of the larger shipments by the carriers they utilize. Freight forwarders are economically regulated by the CAB or the ICC and assume liability for all shipments they accept. (See Taff, pp. 97-100.)

**Hybriding** - A term sometimes used to refer to distribution practices which involve some intermediate handling of shipments which is in addition to the usual transportation services of a common carrier. More specifically hybriding is used to refer to
(1) consolidation of freight into volume quantities at a single point for shipment to only one or two destinations
(2) shipment of a volume quantity of orders to a shipper's agent who will distribute them and (3) the use of consolidating agents by smaller shippers to achieve the volume necessary to achieve the benefits of consolidation. (Vreeland)

**ICC** - Interstate Commerce Commission

**Incentive Rates** - So called because they are intended to provide an incentive to shippers to load vehicles to capacity by offering a lower per hundredweight rate for shipments heavier than the usual truckload minimum weight. (See Flood, pp. 173-174.)

**Interline Service** - "Provision of intercity transportation services for a shipment by two or more common carriers." - Schuster.

**Interstate Commerce Commission** - The United States agency responsible for the economic regulation of rail, motor carrier, inland water, and pipeline transportation services.

**Less-Than-Truckload Shipment** - A shipment of a quantity which does not qualify for the truckload shipment rate. Less-than-truckload shipments are normally processed across the platform at carrier terminals and moved under class rates. (Flood, p. 115.)

**Line-Haul Transportation** - Refers to the through transportation service from origin to destination.

**LTL** - Less than truckload.

**Marriage Rule** - According to Flood (p. 266) this rule "...authorizes the loading of separate cars at the point of origin and at points for partial loading which are considered intermediate to destinations. Instead of stopping in transit a partially loaded car for additional loading, the railroad tenders
another car to pick up the additional freight, the first car being allowed to move directly to destination. The billing nevertheless shows the 'marrying' of these two cars for purposes of obtaining the benefits of the stopping-in-transit privilege, in particular the lowest rate." No time is lost in transit because the car does not actually stop in transit and the freight at the stop-off point does not have to be held until the car containing the freight from point of origin actually arrives at the stop-off point. (See Flood, pp. 265-266.)

**Minimum Charge Shipment** - A shipment which is of insufficient quantity to qualify its rate being computed on a weight basis. (See Flood, p. 111.)

**Mixed Carload** - According to Flood (p. 109) this is a shipment which consists of two or more articles for which the same or different rates or minimum weights apply. Charges are determined by applying the straight carload class or commodity rate applicable to each article in the mixed carload and any deficit in the minimum weight will be charged for at the highest carload rate applicable to any article in the mixed carload.

**Mixed Packages** - If one package contains more than one article, the applicable rating will be that provided for the highest classed article in the package. Only the highest rated item need be shown on the bill of lading. (See Flood, p. 109.)

**Mixed Truckload** - A shipment which consists of two or more articles for which the same or different rates or minimum weights apply. Charges are determined by applying the straight truckload class or commodity rate applicable to each article in the mixed truckload and any deficit in the minimum weight will be charged for at the highest truckload rate applicable to any article in the mixed truckload. (Flood, p. 109.)

**Motor Carrier Split Pickup and Delivery** - The same as stop-offs en route to load or unload except that the stop-off is made within the commercial zone of the origin (split pickup) or the destination (split delivery). (See Newbourne, p. 24.)

**Multiple Shipment Tender** - The concurrent tender of two or more shipments with different consignees to a carrier in the same pickup. (Newbourne)
Operating Ratio - The ratio of the operating expenses incurred in providing motor carrier transportation services to the revenues received for performance of those services. (Schuster)

Order Consolidation - The combining of two or more orders to make a larger shipment.

Order Cycle - The time span from recognition of the need to place an order to the time the product is placed in stock.

Overflow Provision - When a volume or truckload shipment, because of its quantity, exceeds the amount that can be loaded in a single trailer, the minimum charges on each fully loaded trailer and on the excess which does not fully load a trailer will be charged for at the applicable volume or truckload rate at actual weight. This provision is not always available. (See Flood, p. 119.)

Package - A shipment weighing more than twenty pounds but less than fifty pounds. (See Dixon, p. 29.)

Package Freight - Any shipment weighing more than fifty pounds but less than 500 pounds. (See Dixon, p. 29.)

Parcel - Any shipped item weighing less than twenty pounds. (See Dixon, p. 29.)

Peddle Trip - An Intercity trip made outside of a commercial zone between terminals on a carrier's system of routes with additional stops made at consignees/consignors for the purpose of picking up and delivering freight. A peddle trip involves a combination of line haul and pickup and delivery services. (Schuster)

Pickup and Delivery Trip - A trip made within the commercial zone where a carrier maintains a terminal for the purpose of picking up and delivering freight. (Schuster)

Pool Car - Where a shipper combines any number of separate LCL shipments to different consignees into one carload shipment to one consignee, usually a public warehouse offering pool-car unloading and reshipment service. The total transportation charges, line haul and beyond, and the handling charges should be lower than total separate LCL charges. (See Flood, p. 56.)
Pool Car or Pool Truck Distributor - A shipper's agent which accepts consolidated shipments, unloads and sorts them and distributes or arranges for the distribution of the individual consignments within the consolidated shipment. The distributor is often a public warehouseman and usually levies a handling and transportation charge.

Pooling - Sometimes used to refer to the combining of two or more less-than-volume shipments to form a larger but still less-than-volume shipment. (Newbourne) This term implies that consolidation results in a volume shipment.

Pool Point - See Break-Bulk Point

Pool Truck - Where a shipper combines any number of separate LTL shipments to different consignees into one truckload shipment to one consignee, usually a public warehouse offering pool-truck unloading and reshipment service. The total transportation charges, line haul and beyond, and the handling charges should be lower than total separate LTL charges. (Flood, p. 56.)

Processing in Transit - See Transit Privileges

Rail Split Delivery - The shipper can specify delivery of a shipment to one or more parties at freight station platforms, or delivery at private sidings by switch service, or reforwarding a portion of a shipment via rail carriers to some point or points beyond the destination of the car. (See Flood, pp. 262-268.)

Rate Break - The weight at which the total transportation charges for a shipment are lowered by taking the rate associated with the next highest minimum weight thus creating a deficit weight.

Regular Route Common Carrier - A motor carrier who provides transportation service over specified routes between fixed termini.

Shipment Consolidation - The combining of two or more shipments to make a larger shipment.

Shippers' Associations - Part IV of the Interstate Commerce Act, which regulates freight forwarders, defines this term when it states in Section 402(c)(1) that the provisions of this part of the act do not apply to the operations of a shipper or a group or association of shippers in consolidating or distributing freight for themselves or for the members thereof.
on a nonprofit basis for the purpose of securing the benefits of carload, truckload, or volume rates. Thus shippers' associations are not economically regulated by the ICC.

Shipper's Agent - Shipper's Agents are exempted from regulation by the ICC by Part IV, Section 402(c)(2) of the Interstate Commerce Act which states that the provisions of that part of the act which regulate freight forwarders do not apply "...to the operations of a warehousemen or other shipper's agent, in consolidating or distributing pool cars, whose services and responsibilities to shippers in connection with such operations are confined to the terminal area in which such operations are performed." Therefore a shipper's agent accepts no in-transit liability and has nothing to do with the shipment at the other end of the movement. He cannot exercise any operational control or have any active or beneficial interest in the shipment outside of the terminal area.

Small Shipment - A shipment weighing less than ten thousand pounds.

Specialized Small Shipment Agencies - A firm which is licensed solely for the purpose of providing certain specified transportation services for small shipments. The United Parcel Service (UPS) is an example of a specialized small shipment transportation agency.

Stop-off - See Stop-off-in-Transit

Stop-off-in-Transit - A privilege whereby the shipper can specify that a shipment can be stopped somewhere intermediate to the origin and destination to complete loading or to partially unload. The maximum number of stops is usually specified by the carrier. The shipper pays the highest rate applicable on the entire shipment from an origin point to a destination plus a special charge for each stop in transit. (See Flood, pp. 256-273.)

Storage in Transit - See Transit Privileges

Terminal Costs - Motor carrier costs other than line-haul transportation costs which include pickup and delivery, platform handling and billing and collection costs.

Traffic Lane - An origin-destination pair connected by the line haul routes of a carrier.
Transit Privileges - Privileges which allow the shipper to arrange for the stopping of carload lots of goods en route for commercial processing or storage, without incurring a freight rate penalty. (See Flood, pp. 274-277.)

Transloading - According to Flood (p. 256) under this privilege, "...the shipper of a carload shipment to be stopped in transit for partial unloading may request the carrier to unload at an intermediate point that portion of the shipment consigned to the stop-off point and reload it into a separate car (or cars) to be forwarded to its destination." Transloading can result in much faster transit times than a rail stop-off because there is no delay at the stop-off point.

TL - Truckload

Truckload Shipment - A shipment of sufficient quantity to fill a large portion of the trailer of a line haul vehicle and qualify for the truckload freight rate. Truckload shipments are not normally interchanged between vehicles at carrier terminals.

Variable Costs - Costs which fluctuate in accordance with some functional relationship with the level of output.

Weight Bracket - A range of shipment weights.
APPENDIX B

RATE INCREASES ON GLASSWARE

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Lancaster, Ohio  43130
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APPENDIX C

Lists of Factors to Consider in a Consolidation System

I. Location Factors
   A. Plant locations
   B. Warehouse locations
   C. Supplier locations
   D. Customer locations
   E. Breakbulk points
   F. Consolidation points

II. Demand Factors
   A. Spatial demand variations
   B. Temporal demand variations
   C. Customer imposed constraints
      1. Order sizes
      2. Requested shipping
      3. Customer service requirements
      4. Routing requirements
      5. Emergency or expedited orders required
   D. Terms of sale common in industry

III. Transportation
   A. Transportation mode alternatives
   B. Shipment staging space in system
   C. Vehicle capacities
   D. Transit times
   E. Equipment availability
   F. Tariff provisions for missing different products
   G. Transportation companies available
   H. Common carrier rate structure
   I. Special transportation services available

IV. Legal Factors
   A. Middlemen available
   B. Regulatory agencies such as the ICC, CAB, EPA and etc.

V. Internal Factors
   A. Order cycle time capabilities
   B. Customer service standards
   C. Level of unitization
   D. Organization structure
   E. Expertise to plan and operate a consolidation system
   F. The accounting system
G. Products
1. Weight
2. Cube
3. Fragility
4. Compatibility with other products
5. Security requirements
6. Packaging requirements
7. Value

Special Transportation Services Available to Facilitate Consolidation*

Transit Privileges to Store or Manufacture
Stop-off in Transit to Load (Stop-off)
Stop-off in Transit to Unload (Stop-off)
Split Pickup
Split Delivery
Marriage Rule
Pool Truck
Pool Car Transloading
*See Appendix A for definitions

Middlemen Which Facilitate Consolidation

I. Shippers' Agents
   A. Freight Forwarder, Surface or Air
   B. Pool Distributor
   C. Public Warehouse
   D. Consolidator
II. Shippers' Association or Cooperative
*See Appendix A for definition
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