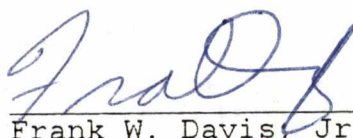


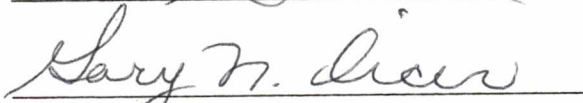
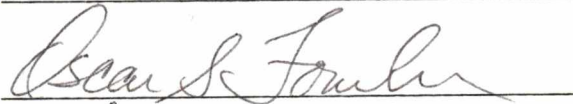
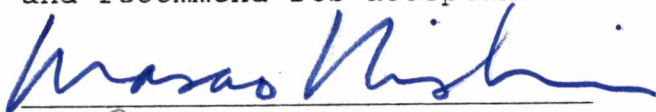
To the Graduate Council:

I am submitting herewith a dissertation written by Prabir Kumar Bagchi entitled "An Analysis of Freight Consolidation in Inbound Logistics." I have examined the copy of this dissertation for form and content and recommend that it be accepted in partial fulfilment of the requirements for the degree of Doctor of Philosophy, with a major in Business Administration.



Frank W. Davis, Jr., Major Professor

We have read this dissertation
and recommend its acceptance:



Accepted for the Council:



Vice Provost
and Dean of The Graduate School

AN ANALYSIS OF THE IMPACT OF FREIGHT CONSOLIDATION
IN INBOUND LOGISTICS

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Prabir Kumar Bagchi

June 1986

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ABSTRACT

Although extensive attention has been given to the use of break bulk terminals and distribution centers, little attention has been given to the use of consolidation centers for reducing acquisition cost and regulating the flow of inbound materials. The control of acquisition cost and the regulation of inbound flows are fundamental to just-in-time manufacturing, meeting foreign competition, and the design of more imaginative and cost-effective transportation strategies now available under relaxed governmental regulation.

This study used the following:

1. an inbound data base of approximately 6,000 actual shipments received by a large mail order and catalog merchandiser;
2. actual transportation rates provided by an on-line rating service; and
3. a simulation model to examine the impact of key consolidation decisions on acquisition cost and customer service.

The key consolidation decisions included: (1) number of consolidation centers, (2) area served by the consolidation center, (3) strategy for release of consolidated shipments,

(4) mean shipment weight, and (5) vendor concentration. Model outputs include variables such as total acquisition cost, transit time from supplier to final destination, variation in transit time, and vehicles arriving at destination center. Simulation ranges included single and multiple consolidation centers, consolidation radius varying from 100 miles to 200 miles, release strategies varying from 1 to 7 days and various shipment sizes and vendor concentrations.

Although this research was based on a specific data set for a specific organization, it does present a methodology and programs for simulating flows from other organizations, and results showing the impact of each of the consolidation decisions on cost, transit time and variation in transit time. Based on this data set one day holding time tended to be more expensive than direct shipment, but cost decreased with longer holding times. As can be expected, consolidation becomes more effective as vendor concentrations within the consolidation area increases. Vendor concentration was the key factor for a consolidation program to be cost-effective in a just-in-time environment. Delivery time generally decreased with consolidation. Delivery time variability was heavily influenced by vendor concentration.

This dissertation makes three major contributions:

1. It illustrates the effect of consolidation parameters on cost, delivery time and variability of delivery time for a given organization;

2. It provides a framework for management consideration of an inbound consolidation program;
3. It provides a model and methodology that can be used by other organizations to analyze data sets specific to their organizations.

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CHAPTER 1

BACKGROUND

1.1 INBOUND MATERIAL CONTROL

A major function of Materials Management is the transportation of inbound materials, both raw materials and component parts at the right time, to the right place and at right cost. Depending on the type of industry, the cost of transportation of inbound materials may easily be 50 % or more of the total cost of material. For example, in the steel industry the percentage cost of transportation of inbound materials will be substantially higher than that of the electronics industry. For a steelmaker, the cost of transportation of inbound materials, according to Gilbert et al. (1983), can easily be 50 to 70 % of the total cost of material. A close examination of a firm's material purchases reveals that inbound material transportation is often¹ controlled by the suppliers because of pricing on a delivered cost basis; although the associated costs are ultimate-

¹ In a National Association of Purchasing Management survey it was revealed that in about 50 % of the companies surveyed, the prime responsibility for inbound freight did not rest with the buyer department. For further information see Purchasing, April 14, 1983, pp. 43-73.

ly borne by the buyer. As a result, it is not uncommon to find different materials being received around the same time from different sources located in the same region. It would therefore seem logical to consolidate inbound materials at a convenient location, in order to reduce the costs of transportation. Also, by taking charge of the inbound supply channel, the buyers can gain better control of the procurement functions and thus increase operational flexibility. They may thus realize substantial savings in the overall delivered cost of inbound materials. In the following discussion therefore, we shall have a closer look at the concepts of freight consolidation, in general, and the relevance of these concepts for the consolidation of inbound materials vis-a-vis the present environment in the transportation industry.

1.2 FREIGHT CONSOLIDATION

According to Newbourn (1980), "One of the first lessons of industrial traffic management is that two and two do not always -- or even usually -- make four in the shipping of freight." Consolidation² of freight actually stems from

² According to published literature, the term "freight consolidation" as used in this research, actually means two separate and distinct operations: "pooling" and "consolidation". According to Newbourn (1980):

Pooling refers to shipments so small that it becomes a question of the ability of carriers to handle them economically and efficiently on a

the above reality. In general terms, consolidation of freight involves grouping of two or more shipments from one or more shippers to form a single large shipment. There may also be multiple destinations. If there is more than one destination, the large shipment usually has to go through a break-bulk point before it is delivered at the final destination. Consolidation of inbound freight involves the grouping of shipments from different suppliers into a large shipment at a convenient point, designated as a consolidation center. In this research, it has been assumed that the organization of the whole process of consolidation would be initiated by the recipient of the shipments.

The consolidation of inbound freight has several advantages. First, firms are able to obtain a local presence to collect, coordinate and follow-up on suppliers. This serves as an early warning system when suppliers expect delays since it is known before the actual shortfall takes place at the consumption point. Besides, in case of an imminent reduction in requirement of an item, early warning often helps

direct door-to-door basis.

In general, the objective of consolidation proper is to transform LTL (less than truckload) and LCL (less than carload) shipments into truckload and carload ones, whereas pooling may be designated merely to increase to size an aggregation that may remain LTL/LCL in total.

In this research however, all aggregation of freight will be considered under the broad term of freight consolidation.

in rescheduling supplies.

Second, firms can reduce transportation costs by achieving high volume rates. It is considerably less expensive to procure inbound materials in a single TL (truck-load) shipment than several LTL (less than truck-load) shipments. This is due to the existence of strong economies of scale in transportation costs. Procurement via a consolidation center involves consolidating different parts from different suppliers in a central consolidation center. The location of a consolidation center would depend upon factors like, part characteristics, volume of procurement, density of suppliers in the region etc. Figure 1.1 and 1.2 illustrates the procurement via a consolidation center.

The consolidation center may either be an existing warehouse, a rented facility (public warehouse), or a distribution center. Parts produced at different origins and meant for one destination are consolidated at the consolidation center for dispatch to the destination. The advantage lies in lower transportation costs and lower inventory costs at the destination, while the disadvantage results from the inventory and material handling costs as well as overhead costs at the consolidation center.

The rate classification structure promotes consolidation. Carriers have consistently maintained considerable rate differentials on small and large shipments. It is com-

Origins(Suppliers)

Destination(Plants)

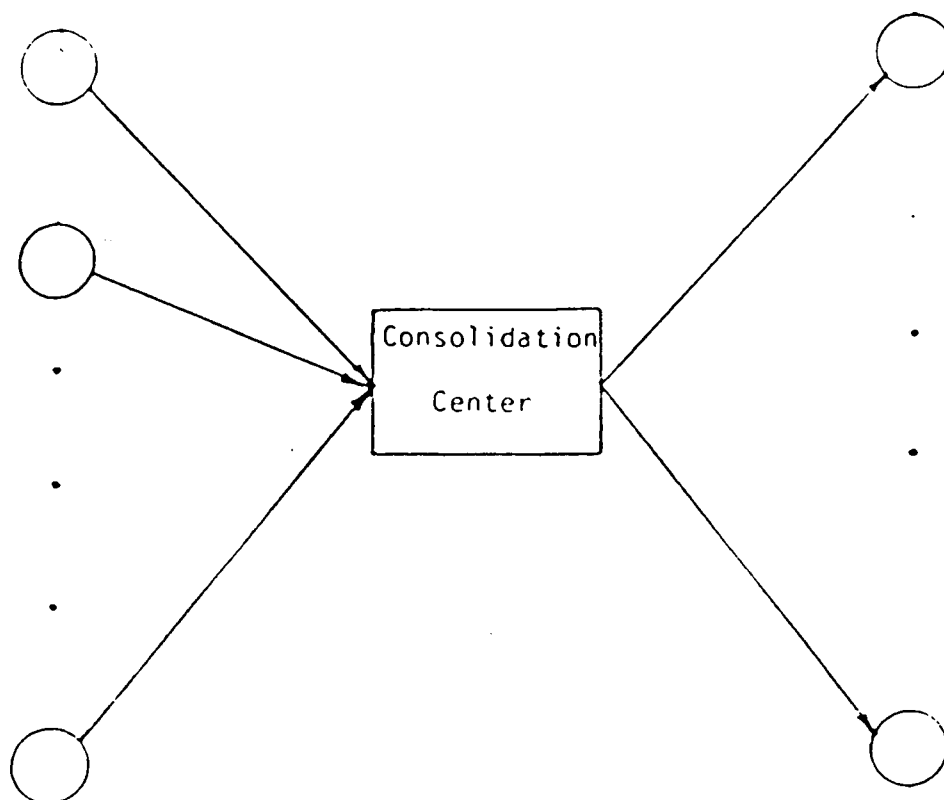


Figure 1.1: Material Flow in Inbound Freight Consolidation

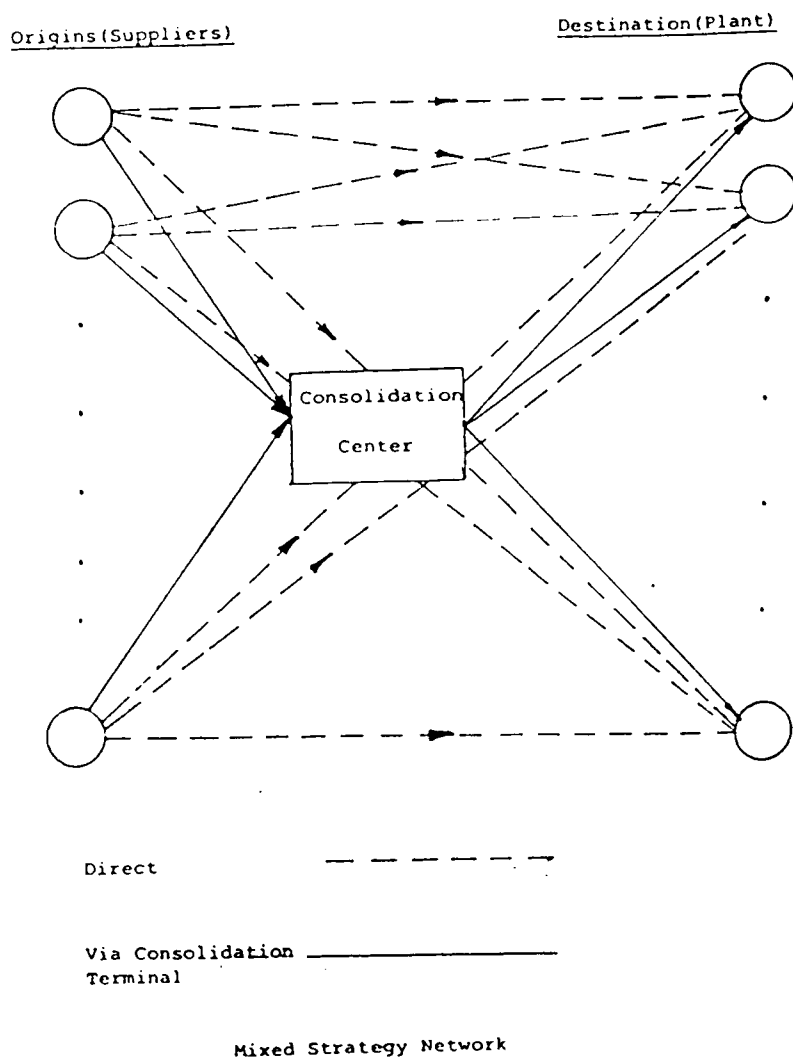


Figure 1.2: Material Flow in Inbound Freight Consolidation-Mixed Strategy

mon to pay more per unit weight for a small shipment than for a larger shipment of the same item. According to the National Motor Freight Classification (NMFC), the classification rates roughly reflect actual rate differentials: thus, if the class 100 rate on a certain item is \$1.00 per hundred pounds, the class 50 rate will be approximately 50 cents per hundred pounds. The following example by Newbourn (1980) will further clarify the matter:

Certain iron rubbish burners with bodies attached or detached move at class 55 in truckload quantities, class 200 in less than truckload (LTL) lots.

In LTL volumes, plastic or rubber expanded tubing can take a rating as high as class 300; shipped in truckloads, the rate can drop as low as class 45.

Although, the above are some of the more extreme examples, the average LTL class rating, according to Newbourn (1980) is probably about double of average TL (truckload) ratings, and the differential is often greater. The following example from Newbourn (1980) would illustrate the point further.

To demonstrate what these rate differentials can mean to the shipper in terms of actual dollars and cents, consider one of the commodities with a relatively small LTL/TL variance: Bottle caps. In a given week a manufacturer may ship out 30,000 pounds of these caps from his plant to one particular destination. If he does so all at once, he is eligible for the truckload classification rating (class 35); which bears a 30,000 pound minimum weight. Assuming the class 35 rate between the two points involved to be 35 cents per hundred-weight, this works out to \$105.00 for the weekly shipment.

However, the production line may be turning these caps out at the rate of 6,000 a day. Should the shipper choose to send them out daily, rather than accumulating them over the course of the week, he must pay the LTL rate (based on a class 55 rating) for each of the five separate daily shipments. The class 55 rate will be about 55 cents per 100 pounds, bringing the daily transportation bill to \$33.00 - and the weekly bill to \$165.00, or \$60 per week (\$3, 120 per year) more than he would have paid had he consolidated his shipments into truckload lots. On a percentage basis, this means his transportation costs are 58 % higher than they need be.

Third, firms can obtain an overall reduction in inventory level by achieving just-in-time scheduling even when suppliers are located all over the country. In order to be able to appreciate how consolidation of inbound freight is likely to aid in achieving just-in-time inventory objectives, a discussion of the just-in-time concepts may be worthwhile.

1.3 JUST-IN-TIME SCHEDULING

One inventory control technique that has recently attracted the attention of the industry is the just-in-time scheduling (hereinafter referred to as JIT). One of the aims of JIT is to provide parts in small quantities, ideally one at a time, rather than in lots, just in time to go into production. Traditional inventory theory on the other hand, advocates delivery in economic lot sizes in order to distribute the high fixed costs over a large number of compo-

nents. The basic characteristics of the JIT³ that can be attained with judicious inbound material consolidation are the following:

1. High frequency of delivery, and reduced shipment size,
2. Reduced, ideally zero safety stock, and
3. Reduced variation in delivery time.

With the attention of industry on JIT techniques , the shipment sizes have started shrinking and the frequency of deliveries have started growing. The consolidation center concept therefore, will be an important step in the right direction. When suppliers are scattered all around the country, multiple deliveries in LTL loads direct from suppliers, (to attain the 'just-in-time' inventory concept) seem impractical and thus pose a serious impediment to the lowering of inventory levels. Consolidation centers would help consolidate such shipments and enable the buyer companies to obtain volume rates. In a just-in-time environment purchasing managers are looking for ways to become more competitive by reducing shipment sizes and increasing the frequency of deliveries without sacrificing the reliability of supplies. Consolidation may prove to be the ideal tool in such an environment. Moreover, when working with little or

³ In fact, there is much more to JIT system than the above characteristics. In this study we are concentrating on the JIT interfaces with inbound material transportation function in particular.

no buffer stocks, this method may give the purchasing manager a better control of the supply channel and thus on the on-time delivery performance. A recent report in Traffic Management (1984) strengthens this viewpoint.

Interest in the Japanese 'just-in-time' approach to production, where deliveries are tightly scheduled to arrive virtually at the moment of need, has led many executives to look more closely at their own companies' practices.

"This is particularly evident in the automotive industry, " . . . "Both General Motors and Ford are scheduling dies for receipt two days in advance of final assembly. which tells us that there is a sharpening of focus on inbound at this time."

At this stage it must be understood that to be beneficial, certain preliminary conditions must be satisfied before freight consolidation is possible.

1.4 WHEN IS FREIGHT CONSOLIDATION POSSIBLE?

First and foremost, freight consolidation will be possible if the individual shipments can be packed in the same truck, trailer or car for at least part of their haul from origin to destination. The simplest and the most profitable proposition however, takes place when the individual shipments share the same truck, trailer, or car for the entire journey from origin to destination. In a snap survey, electronics manufacturers, like Hewlett-Packard, Northern Telecom etc., indicated that major portion of their inbound freight are small loads and present opportunities for consolidation.

The shipper's ability to consolidate freight depends on several factors: line-haul distance involved over which the shipments will move as a consolidated unit, the geographic dispersion of the multiple origin and/or destination points, the cost and managerial problems of setting up and maintaining suitable terminal facilities, etc. To cite some extreme examples, consolidation will probably not prove feasible for small shipments emanating from numerous points scattered over Massachusetts and destined to points, all over the state of Connecticut; on the other hand, consolidation is clearly indicated where the shipments originate in and/or around Los Angeles and are dispatched to New York City. The exact location where consolidation will provide sufficient economic justification to warrant its establishment depends on various conflicting factors. However, certain basic ground rules, like line haul distance and concentration of suppliers in a certain region, are factors of considerable importance.

1.5 PURPOSE OF THE RESEARCH PROJECT

Logisticians in the past, have focused heavily on the distribution of finished products. In my personal experience however, I was confronted with a very similar and perhaps a more difficult problem in physical supply. An electronics manufacturing company in Calcutta, India received

approximately 100 different category 'A'⁴ items from different suppliers in the Bombay region, approximately 1500 miles away. Because of inconsistent availability and reliability, the company experienced very high telephone expenses towards coordinating and expediting shipments. One solution was to station a company employee at Bombay to coordinate delivery to a local consolidation center and then arrange for low-cost reliable TL (truckload) shipment to the plant at Calcutta. This research builds upon this personal experience and the availability of new analytical techniques, to derive a relationship among the different factors that are involved in the setting up of consolidation centers. The development of models for location of consolidation centers is now possible because of the evolution of on-line data bases; which makes it possible to feed the model with accurate and current transportation and distribution costs so that the models are easy to use and accurately represent the real world conditions. A major premise of this research is that quantitative techniques will make a much greater contribution to the industrial sector when supplied with current data and are used to address real-life problems.

⁴ This company had about 250 such items contributing to approximately 75 % of the total procurement dollars. For a complete discussion on ABC analysis see Fogarty, Donald W. and Hoffmann, Thomas R. in *Production and Inventory Management*, South-Western Publishing Co., Cincinnati, 1983, pp. 171-175.

The proposed research therefore, was aimed towards developing a practical approach to determine:

1. the effect of the number of consolidation centers;
2. the effect of holding time at the consolidation center; and
3. the effect of shipment release strategy on the procurement costs of inbound material.

This research is expected to develop a framework for management considerations in consolidation decisions to derive the following benefits:

1. Reduction in transportation costs by achieving high volume shipments;
2. Reduction of overall inventory level through just-in-time inventory control, even when suppliers are scattered over a wide geographic territory;
3. Increased flexibilities in adapting to changes in market demand, as a result of increased control of the procurement channel and reduction in inventory commitment;
4. Information regarding density requirements for suppliers in a region to justify a consolidation center.

This study will also enable many purchasing managers to obtain an answer to the question, "What is the size and frequency of shipment to request from suppliers to minimize procurement costs without sacrificing on customer service?", in a just-in-time environment.

1.6 RESEARCH OBJECTIVES

This research project will seek to achieve the following objectives:

1. Identify the effects of various shipment and delivery time strategies on the overall cost of procurement in a consolidated shipment scheme.
2. Determine the behavior of overall procurement costs due to changes in the mean shipment weights in a consolidated shipment scheme.
3. Determine the behavior of overall procurement costs as a result of changes in the concentration of supplies in a consolidated shipment scheme.
4. Identify the relations between overall procurement costs and the number of consolidation centers.
5. Determine the effects of holding time alternatives at consolidation centers on transit time and on the variance of transit time.

1.7 WHY THIS STUDY?

Although there have been numerous studies on outbound logistics, there has been little emphasis on inbound logistics. Perhaps, the absence of serious studies on inbound logistics may be due to the environment surrounding the transportation industry in general and management's outlook towards the transportation function in particular. Lack of

attention towards inbound consolidation is well described in a recent study by Jackson (1985) where he concluded:

Findings of this study also suggest that inbound consolidation may be neglected in some firms. Inbound consolidation was not found in as many respondent firms and when it was, it was not nearly as extensive as outbound consolidation systems. These findings can at least be partly explained by the fact that many organizations will have far fewer suppliers than customers and will purchase in larger quantities than they sell.

In order to understand the apparent neglect towards inbound consolidation, the following discussion on the environment surrounding the transportation industry and the management structure of traffic and transportation functions vis-a-vis inbound material procurement, may be appropriate.

1.7.1 Regulations in the Transportation Industry

For a long time purchasing/materials management involvement in the transportation of inbound materials had been obscured by extensive government regulations. Indeed, in the past a good case could often be made that the act of buying transportation for the majority of shippers involved the mastery of rules, regulations, and tariff tables, rather than good procurement practices.

1.7.2 Recent Regulatory Changes in the Transportation Industry

The recent de-regulations⁵ of the transportation industry brought about sweeping changes in the freight business. Some transportation companies went bankrupt. The others who survived the turmoil, came up with innovative ideas about cost/service packages. Shippers now have more flexibility in rate negotiations. The time has come when the buyers of transportation can use leverages such as continued orders, to negotiate lower rates. A recent report in Traffic Management (1984) demonstrates the point.

The Pilsbury Company is one of those companies seeking better inbound freight management. "Prior to deregulation, inbound transportation offered limited options." . . . "Now, we can evaluate our product flows, determine which carriers we want to use, and negotiate appropriate cost/service trade-offs. We are in a position today to manage transportation as a business, rather than merely process paperwork."

In a separate report, Weart (1984) claimed:

Previously, many shippers could not justify consolidation efforts, since the spread between LTL rates and TL rates plus handling and local delivery did not offer any economic incentive. Internal resistance to change was hard to overcome, in view of such small rewards for upsetting such long established practices as "immediate shipment." However, now some shippers are able to profitably consolidate that total as little as 7,000 pounds to 10,000 pounds versus the usual 30,000 to 40,000 pounds that many consider the "magic number."

⁵ The transportation industry is not really de-regulated in the true sense of the term. Most of the economic regulations however, were relaxed with the passage of Airline deregulation act of 1978, Motor Carrier Act of 1980, and Staggers Rail Act of 1980.

1.7.3 Organizational Obstacles

Ask a purchasing/materials manager how much his or her company spends on steel or electronic parts and there is a good chance that he or she will be able to give a precise answer most of the time. In a recent study reported by Trill and Porter (1983a), among purchasing professionals, only 40. % could give any figures about the expenses incurred by his/her company in transportation. This lack of knowledge about transportation costs, according to Trill and Porter (1983b), can be partially explained by the fact that in a majority of the companies, purchasing is not accountable for the choice and cost of transportation.

Recently however, there has been a change in the management's outlook towards the transportation function, and especially towards inbound material procurement as would be evident from the following discussion.

1.7.4 Current Trends in Inbound Material Procurement

Recently, aided by inflation, higher interest rates, and stiff competition from foreign suppliers, managements have been forced to look at inbound material procurement also. Attention to inbound material transportation received added impetus with the recent relaxation of regulations in the transportation industry. As reported by Trill and Porter (1983a), inbound freight consolidation has become com-

mon. Companies are establishing consolidation points where carriers can deposit inbound shipments. Then, after consolidating there, trucks carry them in truck-loads to the plant.

1.7.5 Structural Changes in the Organization

While the importance and opportunities in the above areas are easily understood, there exist many obstacles to overcome before full advantages can be realized. One of the biggest obstacles for purchasing/materials managers is that they are often not charged with the responsibility for buying inbound freight transportation. In many companies, for instance, the responsibility of purchasing transportation is a shared one. In a large number of companies, as reported by Trill and Porter (1983a), the whole area of inbound freight purchasing falls between the cracks; no one is responsible, no one calls the shots, and no one keeps track of how service is performed. Trill and Porter (1983a) reported that in a National Association of Purchasing Management (NAPM) survey only 35 % of the 5,539 responding members reported that the purchasing department was accountable for the choice and cost of transportation. Recently however, there has been some changes in the industry which may require the purchasing department to take full advantage of the opportunities for buying optimum-cost transportation services. These changes are:

1. merger of purchasing and transportation functions;;
2. integration of purchase systems with MRP systems.

The recent merging of the Energy and Materials and the Transportation and Distribution departments into a single materials and logistics department at Du pont and U.S.Steel, as reported by Trill and Porter (1983a), are moves in this direction. In many companies, purchasing and traffic departments are putting together closer co-ordination to achieve the desired results.

Schuldenfrei and Shapiro (1980) describes the inbound material consolidation problem as the reverse distribution problem and suggest similar techniques for solution. According to them, the manufacturing firm is often biased in its organization so that production, marketing, sales, and distribution are largely concerned with the outbound. They went on ... "just as inbound enjoys little staff, so also does it lack in the literature a history of creative problem resolution."

In the recent past, transportation industry has seen a rapid increase of transportation costs. This increase, coupled with the energy crisis, increased emphasis on just-in-time systems, and stiff foreign competition, justify the need to reduce the costs of procuring inbound materials.

In today's just-in-time environment managers often ask, "What is the size and frequency of shipments to ask from

suppliers to minimize procurement costs without sacrificing on the reliability of supplies?". This study is aimed towards providing feasible answers to such questions.

In addition, due to the availability of on-line information systems, it is possible to obtain more accurate transportation costs⁶ rather than assuming a linear cost/weight relationship which was often done by earlier researchers on facilities location. As a result, more realistic results can be obtained from this study.

1.8 LIMITATIONS OF THIS RESEARCH

The results of this study may be limited to a certain extent primarily because of the test environment. The use of simulation instead of studying real systems may raise several questions of appropriateness of the results. In a consolidation problem, which is both dynamic and stochastic, simulation is preferable to study of real-life systems for reasons of cost and time.⁷ Also, once a simulation model is

⁶ In the present research these costs will be available from the on-line data base of Numerax, Inc., 230 West Passaic Street, Maywood, NJ 07607. However, it must be understood that scope of negotiation of rates will still be there. A database such as this one, will help us in obtaining more reliable rates than rates based on linear cost/weight relation.

⁷ See Jackson, George C., in unpublished Ph.D dissertation on "An Experimental Investigation of the Order Consolidation System", Ohio State University, Columbus, Ohio, 1980 for a complete discussion on the use of simulation in a consolidation problem.

built, it can be used repeatedly to analyze various aspects of a consolidation system. Validity of simulation is evaluated against actual performance data. Another validation is done by comparing the model formulation with other consolidation model formulations. The model in this reserach uses similar assumptions and methodology as those of Cooper (1984), House (1979), and Jackson (1980).

The study is also limited to a certain extent since the shipment data used was obtained from a particular firm. Another firm may or may not follow the same type of load distribution. Therefore, the results of this study can only be generalized to specific firms having the same type of load distribution. This need not be seen as a serious shortcoming, since the same model can also simulate other situations with very little changes in the computer coding. Following example may help explain the point:

1. A firm may have a large concentration of suppliers near a different city in the midwestern United States and may have suppliers in a different set of locations. This would necessitate redefining the user-defined probability distribution which gives the frequency of occurrence of the origin zip codes and also a separate set of tariffs for the new location of the consolidation center.

Furthermore, this study in implementing a consolidation scheme, would apparently work well if an organization receives a substantial number of its supplies in the form of LTL (less than truck load) shipments from various parts of the country. At first sight this may appear to be a limitation of the model. However, when we consider the industry's increased emphasis on the just-in-time philosophy it would be clear that this would not really be a limitation. With the just-in-time inventory scheduling system in place, there will be strong pressure on the reduction of the procurement lot sizes and increase in the frequency of deliveries. But, with the reduction in lot sizes, the differential between TL and LTL costs increases. An effective way to combat this situation of increased transportation costs is to consolidate smaller LTL loads into volume loads at a consolidation center. With the availability of sufficient loads at the consolidation center, we may be in a position to increase the frequency of dispatches from the consolidation center. Considering these aspects, we can easily utilize the concepts discussed and the framework presented in this research in a variety of situations.

1.9 GOALS TO BE ACCOMPLISHED BY THE RESEARCH PROJECT

This research is expected to provide a framework for management considerations for the establishment of inbound freight consolidation centers. This study will provide an insight into the relationship between parameters like holding time at the consolidation center, transit time, transit time variance on the total cost of procurement, and the level of inventories. Also, this research will provide an answer to the intensity of concentration of LTL supplies in a region, necessary to be a good candidate for consolidation. What is most important, this study will help enable the purchasing manager to obtain a feasible solution in his quest for lower shipment sizes and higher supply frequency without sacrificing the level of customer service in a just-in-time environment. Apart from these, this research will be complementary to the existing body of literature which happens to be heavily weighed in favor of the distribution side of logistics, and thus this research will attempt to extend the literature.

CHAPTER 2

SUMMARY OF PAST RESEARCH

2.1 PAST RESEARCH ON CONSOLIDATION

Prior published research on freight consolidation is not extensive. Most of the work has been of a proprietary nature and therefore, not reported in the literature. But the potential for substantial savings through the use of freight consolidation has however, not escaped the attention of transportation professionals, particularly due to the small shipment problem.⁸ The beginning of organized research on freight consolidation from the early seventies may be traced to the fact that trucking companies were losing money on shipments of less than 500 pounds.⁹ Also, the efforts of Newbourn (1980) in preparing "A Guide to Freight Consolida-

⁸ See Grabner, John R., "Small Shipments: A Major Transportation Challenge," Tennessee Survey of Business 5, February 1970, pp. 29-33; Hageman, Robert W., "Curing Small-Shipment Headaches," Distribution Worldwide, March 1972, pp. 37-38; Schuster, Alan D., "Shipment Consolidation: The Motor Carrier's Viewpoint," Applied Distribution Research, ed. by Robert G. House and James F. Robeson, Transportation and Logistics Fund, The Ohio State University, Columbus, Ohio, 1977, pp. 17-21.

⁹ See Schuster, Alan D., "An Econometric Analysis of Motor Carrier Less- Than-Truckload Services," Ph.D dissertation, The Ohio State University, 1977.

tion for Shippers" seems to be the culmination of organized thinking on the subject. Newbourn has been able to put forward his ideas of freight consolidation from conception to implementation in a simple easy-to-understand manner. He has discussed the matter in the light of existing tariff structures and the rate classifications and has been able to show how these practices in the industry favor freight consolidation. He has also explained the importance of traffic analysis and planning as well as cooperation from Sales and Marketing in starting a freight consolidation program. In conclusion, he has discussed how implementation of a consolidation program can actually be done and the role of computers in such a program. Unfortunately, he has not reported any real-life case analysis of how helpful was a consolidation program.

Freight consolidation simulation studies by Lai (1974), Masters (1980), and Jackson (1981) concluded that consolidation generally reduced costs as compared to direct shipments except when the order size was too small. In both the Masters and Jackson studies, delivery time increased. Variance in delivery time did not always increase, however, even though an order may have been held for later shipment.

Masters (1980) studied the effects of pooling shipments on customer service for a distribution network of one source and 399 customers. In each simulation run, three parameters were controlled:

1. The number of consolidation points included in the distribution network.
2. The consolidation point to customer assignments.
3. The maximum holding time allowed per order.

The assignments of customers to a particular consolidation center were made heuristically with varying criteria as described below:

1. Minimum cost per order.
2. Minimum distance from the consolidation center.
3. Minimum time in transit.

The performance of the distribution system was measured in terms of cost (\$/cwt), average delivery time, and delivery time variance.

The results by Masters indicate that temporal consolidation reduces cost, increases mean delivery time, and maintains or decreases delivery time variance. According to his study, the order weight was the most important factor in explaining the variation of all the dependent variables like, cost, delivery time, and delivery time variance. Apart from order weight, the number of orders and the design algorithm contributed to the major variation in delivery time, while the number of orders had major effect on the delivery time variance.

Jackson (1981) did a similar study on a one-product, one-plant, and multi-distribution center network. The following variables were considered:

1. The number of consolidation points,
2. The daily number of orders,
3. The shipment release strategy, and
4. The holding time at the distribution center.

An important finding of this study was that consolidation was not at all cost-effective at low order volumes. Shipments of 12,500 orders per year tended to be more expensive than shipments of 50,000 orders per year. The lower volume of orders particularly reflected higher mean delivery times and variances since such orders were kept longer for generation of a sufficient load that could receive better freight rates.

Brennan (1981) presented two deterministic consolidation models. The first one was similar to the familiar EOQ (Economic Order Quantity) model. In addition, a cost versus customer service trade-off was derived. Average delay in delivery per cwt was chosen as the customer service measure. In this model the time and quantity decisions have been shown to be the opposite of the traditional thinking in inventory control. Instead of receiving economic order quantity and using it up gradually, consolidation promotes accumulation of orders up to an economic shipment quantity and then all orders are shipped as a single consolidated shipment. The holding costs are either customer-imposed penalty costs associated with delays and/or inventory carrying

costs. The costs of shipping an order replace the ordering costs in the economic order quantity (EOQ) formula. The rate of demand per unit time is used instead of annual demand.

The second model presented by Brennan was shown to be mathematically equivalent to a Wagner-Whitin algorithm¹⁰ although new planning horizon results were to be developed for consolidation. This model demonstrated the applicability of dynamic programming for the deterministic case.

Cooper (1983) compared several strategies of freight consolidation with field distribution centers, using a combination of facility location and dynamic simulation models. She considered the following distribution systems alternatives: (1) plant to customer, (2) plant to customer through consolidation points, (3) plant to customer through warehouses with consolidation.

The following were the steps followed by her for investigating the alternative systems:

1. A branch and bound integer programming algorithm to select lowest cost warehouse or consolidation point locations;

¹⁰ Wagner, Harvey M., and Whitin, T. M., "Dynamic Version of Economic Lot Size Model," Management Science, Vol. 5, pp. 89-96, 1958.

2. An event-oriented simulation model to determine the distribution costs, mean delivery time, and delivery time variance for each system under different demands;
3. Multivariate analysis of variance to determine the lowest cost systems; and
4. Regression analyses.

The value of this study, as rightly claimed by the author, lies in its ability to compare different distribution systems under several conditions. Among the different distribution systems alternatives considered by the author and mentioned above, systems two and three, freight consolidation from plants were the least expensive but had the longest mean delivery times. The author has concluded that, for companies which primarily ship high-valued products, consolidation is likely to prove beneficial, although the decision to consolidate should be preceded by a consideration of the likelihood of increase in delivery time. Cooper's study however, does not focus on the consolidation strategies for the inbound freight.

One of the proprietary studies in freight consolidation is the CNET model of Logistics Resource, Inc.¹¹ The intent of CNET is to determine the most economical choice of consolidation points and break-bulk points for handling a set

¹¹ Logistics Resource, Inc. is an independent consulting service of Leaseway Transportation Corporation.

of LTL shipments. The model assumes that a set of LTL shipment generated over a fixed time period (for example, one week) is given.

The model is also given a set of potential consolidation points and break-bulk points. The model then determines how these LTL shipments might be combined at candidate consolidation points, and subsequently divided at candidate break-bulk points. The model attempts to minimize valuable transportation costs, which includes the LTL costs to move products from the sources to the consolidation points, and from the break-bulk points to the destination, and the TL costs between consolidation points and break bulk points. The solution of the CNET model is obtained through a combination of heuristics, or an approximate solution procedure for obtaining a starting solution, and then through mixed-integer linear programming solved by the branch and bound method. A critical analysis of this model is not possible since the computer code is not available in the literature.

From the applications point of view, freight consolidation programs have been successfully practiced in some companies. Notable among them are the COLTRAN ("Columbia Transportation") and COLAIR ("Columbia Air"), the two successful nationwide CBS¹² records consolidation programs which serve vendor and interplant freight. As reported in

¹² Columbia Broadcasting Service, Inc.

Traffic Management (1979) "Virtually all CBS Record individual shipments are LTL in nature, although the COLTRANS and COLAIR programs handle well over half of vendor and interplant tonnage in volume movement." These consolidation schemes have existed for more than a decade and these have grown despite temporary setbacks. In the manufacturing sector, electronics giants like, Hewlett-Packard, Northern Telecom etc., who receive 80¹³ % or more of inbound freight in the form of LTL shipments, have started consolidation programs of their own. However, critical analysis of these consolidation programs is not possible since not much is reported regarding the working of the consolidation scheme.

2.2 PAST RESEARCH ON FACILITIES LOCATION

Much effort, both quantitative and qualitative, has been given to the problem of optimizing outbound logistics costs. Numerous articles have appeared in different journals regarding sophisticated techniques for solving outbound distribution problems. But, there have hardly been any studies on the inbound logistics problem. Since the early work of Alfred Weber, (1929) there have been numerous studies on the facilities location problem. Most of these

¹³ In a correspondence with the author, Hewlett-Packard informed that 80 % of its inbound materials are received as LTL shipments. In a similar correspondence, Northern Telecom confirmed that 100 % of its inbound materials are received as LTL shipments.

studies center around finding the location of either distribution centers or production facilities. Broadly speaking, previous research on the location-allocation problem can primarily be grouped into three different classes: heuristic approaches, mathematical programming approaches, and simulation approaches.

2.2.1 Heuristic Approaches

There have been many heuristic¹⁴ solution techniques presented in the literature. The sheer volume of this research precludes a detailed examination of each work. In this review we shall, therefore, present a few of the most widely cited papers.

Of all the heuristic approaches to the location-allocation problem, the pioneering contribution has perhaps been made by Kuehn and Hamburger (1963). Their model consists of two parts : (1) the main program locates warehouses, one at a time until no additional warehouses can be added to the system without increasing the total costs, and (2) the bump and shift routine which attempts to evaluate the profit implications of dropping or shifting warehouses which were

¹⁴ According to Chentnik (1980), "A heuristic is a method of education in which the pupil is trained to discover things for himself.... it connotes a code with which computer "learns" to arrive at a good solution. The major output of such a technique is the knowledge that problem complexity can be reduced if various "discovered" procedures are followed."

added previously with the idea of modifying the solutions obtained by the main program.

Three heuristics were used in their model. These were: (1) A warehouse should be located at or near a concentration of demand. (2) Near optimum warehousing systems can be developed by locating warehouses one at a time, where the warehouse added contributes the least cost to the total system. (3) The location of a warehouse near a high demand area enables us to restrict our search to a small subset of all possible locations.

Feldman, et al. (1966) presented a modified and extended version of the Kuehn-Hamburger model. The most important extension was to allow the economies of scale to affect warehousing costs over the entire range of warehousing sizes, rather than having a single fixed cost for opening a warehouse. In other words, they assumed that the warehousing cost is concave, rather than the sum of a fixed cost and a linear operating cost.

The solution technique used both an add routine and a drop routine. The add routine starts with all warehouses closed, and successively adds one after another, while the drop routine starts with all warehouses open and successively closes them. According to Chentnik (1980):

The advantage of this method over Kuehn's is its ability to consider concave and different regional warehouse costs.

Despite this improvement, the model suffers from the basic assumption that the transportation costs are linear. In other words, like the Kuehn-Hamburger model, this model fails to recognize the reality that per unit transportation costs do change with the shipment size.

Manne (1964) utilizes as a heuristic device a somewhat altered version of the "Steepest Ascent One-Point Move (SAOPMA)" algorithm developed by Reiter and Sherman (1962). He built vectors of ones and zeros (one representing an open plant and zero representing a closed plant) to define a unit hypercube. A lattice represented the market centers in a unit hypercube, and fixed operating costs as well as proportional transportation costs were specified for each potential location. Then, starting with an arbitrary lattice point, the SAOPMA algorithm searches for the adjacent feasible lattice points that produce the maximum improvement. For example, if the vector (0 0 1 0) represents the arbitrary starting point, a search would be made among vectors (1 0 1 0), (0 1 1 0), and (0 0 1 1) to determine which, if any, combination leads to an improvement. If none shows any improvement the algorithm terminates. Otherwise a point is chosen and the search is repeated.

Manne seems to have been able to reduce computation time for the class of problems investigated, and obtained a tolerably close approximation to the global optimum. A heu-

ristic technique can never guarantee that an optimal solution will be achieved. This technique is no exception. But it does produce a local optimum result. Despite many positive attributes of his model, it has one major deficiency. The model considers a single rate of transportation irrespective of product type or volume. In the real world situation this is hardly ever true. The cost of transportation, being the single most important factor in distribution merits more detailed attention.

2.2.2 Mathematical Programming Approaches

Within the area of mathematical programming approaches, there appears to be a great deal of attention given by management scientists in the recent past. Notable among these are the works of Akinc and Khumawala (1977), Balinski (1964), Ballou (1978), Baumol and Wolfe (1970), Efroymson and Ray (1966), Geoffrion and Graves (1978), Sweeney and Tatham (1976). In general, all these studies except the last one, involved a mixed integer programming formulation with a fixed charge associated with the utilization of a facility. These efforts thus differ basically in their manner of handling the objective function.

Akinc and Khumawala utilizes a branch and bound procedure with increased efficiency obtained through the development of dominance criterion, lower and upper bounding proce-

dures, and branch and node selection rules utilizing the special structure of the problem.

Balinski employs a partitioning theorem of Benders (1962) to reduce the problem to that of solving a sequence of increasingly more complex integer programs.

Ballou uses a decomposition linear programming approach. His model, known as DISPLAN (DIStribution PLANner) is a computer model which deals with a broad range of logistics systems planning questions, such as:

1. What is the best number, location, and size of the warehouses in a logistics system?
2. What are the best patterns with which to distribute to customers through warehouses and plants subject to capacity and location constraints on plants, and delivery constraints on customers?
3. What is the effect on logistics and production costs of increasing or decreasing production capacity at existing or at new locations?
4. What is the effect on logistics and production costs of dropping or adding a warehouse?
5. What shifts occur in product flow patterns as changes occur in production, transportation, warehousing, inventory, and order processing costs?
6. What are the best product loadings on plants?

7. What is the impact of price policy on warehouse location and of warehouse location on price policy?

Efroymsen and Ray have developed a solution technique which uses a branch and bound algorithm for the simple facilities location problems. The presence of fixed charges per unit for open facilities does not allow a linear programming approach. In the branch and bound algorithm, initially the binary restrictions are waived and the problem is solved as a linear program to obtain a lower bound in a minimization problem. Then branching is performed on the non-binary variables, using the following rules.

1. Find a minimum bound for the cost reduction of opening a facility. This is obtained by finding out the reduction in the cost of transportation obtained due to opening of the facility, and subtracting the fixed charge associated with the opening of the facility. If this is positive, treat the facility as open.
2. If a given demand can be supplied cheaper from one of the open facilities, do so.
3. Find a minimum bound for the cost reduction of opening a facility. If it is found to be negative, close the facility.

Efroymsen and Ray further state, that the technique has been tried on problems with as many as 50 plants and 200 customers. Extensions of the technique were offered to han-

dle certain other related problems, especially the n segment linear concave cost function.

Baumol and Wolfe devised a simplified technique, similar to the transportation algorithm, to obtain a local optimum in warehouse location problems having a non-linear (concave) objective function. The assumption of known demand at each geographic region is used, while at the same time, allowing the number of warehouses to vary. Although in many ways similar to the transportation algorithm, their technique incorporates three refinements:

1. the possible non-linearity of the cost functions;
2. the presence of warehouse capacity constraints; and
3. the routing of each flow out of a plant through a warehouse to a customer.

This technique has an advantage in its ability to consider non-linear costs, arising out of the transportation rate structure, as any shipment small enough to necessitate less than truck load lots, will move at higher rates. Problem size however, may seriously hamper the economy of computations.

Geoffrion and Graves (1978) developed a general two-stage multi-commodity distribution system model,¹⁵ using

¹⁵ The original model was developed for Hunt-Wesson Foods, Inc. and was first discussed in Geoffrion, Arthur M. and Graves, Glenn W., "Multicommodity Distribution System by Benders Decomposition," Management Science, vol. 20, no. 5, January 1974, pp. 822-844.

mixed integer linear programming and Benders decomposition along with a commodity bundling structure. The original model has been modified and vastly superior performance has later been reported in Bradley, Brown and Graves (1977). Broadly speaking, the purpose of the model is to find the distribution system design, that achieves the desired level of customer service at minimum total cost within necessary constraints. A master problem finds a potential configuration of the system, which is then submitted to a set of transportation sub-problems. The sub-problems seek to find better system designs and hence provide the upper bound of the optimal system costs. On the other hand, the master problem improves the lower bounds on the optimal system cost. When the lower and the upper bounds are close enough, measured by a suitable stopping criterion, the best total system design regarded very close to the mathematical optimum, is found and the iteration stops. Products in this model are not considered individually, but instead they are aggregated into bundles in order to reduce the magnitude of the problem to be solved. The model permits a customer to receive different products from different warehouses. Mathematical formulation and description of the notations used in the model have been included in Appendix B.

Sweeney and Tatham in their excellent studies on the long-run model for multiple warehouse location, provide a

synthesis of a mixed integer programming formulation for the single-period warehouse location model, with a dynamic programming procedure for finding the optimal sequence of configurations over multiple periods. The computational time required by any dynamic programming procedure increases linearly with the number of stages and exponentially with the number of states. Therefore, the number of configurations to be considered at each stage is the most critical factor from a computational point of view. By rank-ordering the static solution at each period, and intelligently considering only a few of the best rank order solutions for inclusion in the optimal multi-period solution, they have been able to reduce the computational time to a great extent.

2.2.3 Simulation Approaches

One of the pioneering efforts in distribution center location analysis was at the H.J.Heinz Company. Heinz has factories and distribution centers located all over the country. In the 1950s, major changes took place in customer buying patterns. The principal reason for these changes was the rapid growth of independent grocery wholesaling firms which replaced the direct store deliveries from firms like Heinz. Heinz reduced the number of distribution centers from 68 to 43 between 1957 and 1959. At this stage, **Shycon and Maffei (1960)** came in as consultants to study the prob-

lem and recommend future actions with regard to the location-allocation of distribution centers. They built a simulation model to evaluate the distribution centers in existing locations and some in new locations. The initial model considered 10 alternative location patterns, which were user-specified. Sequential runs of the model led users to "what if" questions, which were later analyzed with additional runs of the model. The preparation of the model for Heinz's complex, high-volume national distribution system required extensive data collection.

Specifically:

- It had to take account of each customer's order sizes, his ordering patterns, the various types of shipments he receives, and his product mix.

- Provision had to be made for handling the costs of the various kinds of shipment made - i.e., carload, less-than-carload, truckload, less-than-truckload, and various shipment sizes within the lower classifications.

- Variation in warehouse operating costs - i.e., labor costs, rentals, taxes for different geographic areas - had to be considered.

- The many different classifications of products which Heinz manufactures, the alternative factory source points for each of these products and the factory capacity limitations on each had to be examined.

- Finally, when such a representation was designed, it had to be in such form that it could be synthetically operated, using real operating figures, for a year's time, over and over again.

In order to reduce computation, a preprocessing program eliminated the volume of shipments which go directly from factories to customers, and hence do not affect the warehouse distribution system. The annual cost savings, as noted by Vollmann et al. (1984), was estimated to be \$ 250,000. According to Vollman et al.

Management found the model very useful, but it was necessary to make certain adjustments for unique considerations not included in the model. These involved things like finding inadequate transportation service in one location, special tax and labor constraints, and a few cases where actual transport costs differed substantially from those assumed for the initial model.

According to Vollmann et al., this model has been further developed and is now called LOGISTEK. The most fundamental change according to them, is that the present model is capable of finding good location choices, rather than merely evaluating a fixed set of locations.

House (1979) developed a simulation model to determine total distribution costs from a predetermined configuration of distribution centers. The model assumes that the user is conversant with the problem environment and has a fair idea as to the locations which are potential candidates for inclusion into the model. The cost components considered comprise, inbound and outbound transportation costs and fixed and variable costs at the warehouse. His model minimizes the total distribution costs for a given set of locations of distribution centers. An additional feature of his model is

that he has included a pre-processing program in his model, which separates truckload or carload orders from the mainstream. This allows direct shipment of such volume orders. His model can handle problems relating to multiple products, multiple plants , and multiple modes of shipment. This feature adds to the flexibility of his model. The greatest weakness of his model, however, is that it does not include any customer service measures.

Markland (1973) has come up with a comprehensive simulation modeling approach to the problem of locating warehousing facilities that minimizes the costs associated with operating a multi-product, multi-source, multi-destination distribution system. Markland's model is derived within the "industrial dynamics" framework. Markland employed product flow as the major control parameter in his dynamic feedback-control mechanism. He divided the production- distribution system into the three following interconnected sectors:

1. Wholesale sector.
2. Production sector
3. Distribution sector

Within each of the three sectors, the following set of variables were considered:

1. Levels -- quantities of product which were measurable when the system was at steady state--for example, inventory levels.

2. Flows-- quantities of product required during a specified time period -- for example, units of product demanded per month at the wholesale level.
3. Delays -- a system characteristic that causes a delay in flow -- for example, the shipping delay from the manufacturing facility to the wholesaler.

In his model, Markland simulated transportation costs associated with a particular shipment, as a function of the weight of the shipment, the mode of shipment employed, and the distance involved in the movement. The warehousing costs were assumed to comprise a fixed charge element, and a variable element. The fixed cost element of warehousing costs, was approximated from existing company data. The variable cost element was assumed to be linear. It was observed by him, that the warehousing configuration which minimized the transportation costs, also minimized the total distribution costs. This result was considered natural in view of the fact that 60 to 70 % of the total cost of distribution was composed of transportation costs. The model utilized input from an existing management information system, and employed a number of relatively simple heuristic procedures to analyze various alternative warehousing networks.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 OVERVIEW

It has been observed by the researcher that the techniques of freight consolidation have not been tested in the inbound material procurement problem. This chapter enumerates the research plan that would be adopted to evaluate certain freight consolidation strategies, especially to achieve the research objectives presented in chapter 1.

3.2 RESEARCH HYPOTHESES

The following research hypotheses have been formulated in order to achieve the research objectives mentioned earlier in chapter 1. An alpha risk of 0.01 will be chosen to reduce the chances of type I errors.

Overall Procurement Costs

H_0 : There is no difference in overall procurement costs among the different shipment strategies at $\alpha=0.01$.

H_1 : Direct unconsolidated shipment scheme, is more expensive than consolidated shipment under different

shipment strategies. .

A review of consolidation literature suggest that consolidation should generally reduce overall procurement costs due to the existence of strong economies of scale in transportation costs. Therefore, the alternate hypothesis ($1H_1$) may be restated in order to be able to compare unconsolidated shipment costs with consolidated shipment costs under different shipment strategies separately. The sub hypotheses are:

$1H_{1a}$: Direct unconsolidated shipment scheme, is more expensive than consolidated shipment with 1 day holding time at the consolidation center.

$1H_{1b}$: Direct unconsolidated shipment scheme, is more expensive than consolidated shipment with 3 days holding time at the consolidation center.

$1H_{1c}$: Direct unconsolidated shipment scheme, is more expensive than consolidated shipment with 5 days holding time at the consolidation center.

$1H_{1d}$: Direct unconsolidated shipment scheme, is more expensive than consolidated shipment with 7 days holding time at the consolidation center.

Mean Transit Time

$2H_0$: Mean transit time of an unconsolidated shipment is

less than or equal to the mean transit time of a consolidated shipment scheme at $\alpha=0.01$.

$2H_1$: Mean transit time of an unconsolidated shipment is greater than the mean transit time of a consolidated shipment scheme.

Transit Time Variance

$3H_0$: Transit time variance in an unconsolidated shipment scheme is greater than or equal to the transit time variance in a consolidated shipment scheme at $\alpha=0.01$.

$3H_1$: Transit time variance in an unconsolidated shipment scheme is less than the transit time variance in a consolidated shipment scheme at $\alpha=0.01$.

From the above hypothesis design, it would be clear that the test has been designed in favour of the null hypothesis or the hypothesis of no difference. In other words, we would not accept the alternate hypothesis (that consolidated shipment results in lower overall procurement costs) unless there is sufficient evidence to reject H_0 .

3.3 RESEARCH PLAN

1. Select¹⁶ a manufacturing or a retailing firm and collect data regarding its inbound material procurement, sources of these materials, location of these sources, the volume of orders, and the transportation costs for all the origin-destination combinations involved. Ideally, this information will be available from a computer data base.

In this study the above information was obtained from a Virginia-based company. The data pertained to less-than-truckload (LTL) shipments originating in the midwestern United States for shipment to five destinations. The LTL shipments data used in this study originated from the states of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Ohio during the period from December 1, 1983 to November 30, 1984. This data was available in the form of printed computer output and was obtained through the courtesy of Logistics Resource, Inc., a Cleveland-based consulting firm. Average truckload shipment weight was considered as 16,000 pounds as advised by the firm from their experience of the types of commodity received by them. Also, class 100 rates were

¹⁶ The firm selected will have to receive substantial number of LTL packages preferably from across the country as its inbound material.

considered as stipulated by the firm.

2. Based on the above information, determine the best configurations of the consolidation centers. This can be done by applying a mixed integer linear programming (MILP) technique as has been shown by a number of researchers in the areas of facility location. A mathematical formulation of the consolidation center location problem is given in Appendix A. In the present research, instead of solving this MILP problem, we have heuristically selected potential consolidation centers. Concentration of suppliers in the region was the principal criterion for such selection. Chicago, Illinois and Cincinnati, Ohio were selected as the locations for the consolidation centers, because Chicago metropolitan region had the highest concentration of LTL suppliers, 41% of the total LTL weight generated in the Chicago area. The Cincinnati area had the next highest concentration, about 29% of the total LTL weight. Table 3.1 shows the weight concentrations within a 100 mile radius of the potential consolidation centers and percent of weight within that area.

TABLE 3.1

LTL Shipment Weight Within 100 mile Radius

Origin	LTL shipment Weight Within 100 mile radius(000 lbs)	% of Total Weight Within the Region
Chicago, IL	3,777	41 %
Cincinnati, OH	2,698	29 %
Terre Haute, IN	1,560	17 %
Cleveland, OH	1,016	11 %

Because of core restrictions, only the first two consolidation centers, e.g., Chicago and Cincinnati have been considered in this study. A block diagram of the cost minimization model showing the associated cost elements is shown in Figure 3.1.

3. Having located the consolidation centers, simulate the physical supply system of the firm with the aid of a computer-based, event-oriented, Monte Carlo simulation model. The physical supply system will be simulated for different shipment strategies as given below:

- a) No consolidation,
- b) Consolidation with one-day holding time,
- c) Consolidation with three-day holding time, and
- d) Consolidation with seven-day holding time,

Source	Consolidation Center	Destination

Total = Transportation + Fixed & var. + Transportation
Costs Cost from costs at the Cost from
source to consolidation Consol. center
consol. center center to destination

Figure 3.1. Cost Elements in the Location Model

4. Evaluate the different shipment strategies in order to answer the research questions posed in Chapter 1. The different shipment strategies and the variables considered in this study have been mentioned in Figure 3.2.
5. In this step a multi-variate analysis of variance will be performed in order to determine whether overall procurement costs including inventory carrying expenses, delivery time, and the delivery time variance are statistically related to the various shipment strategies.

The various steps in this research plan has been shown in the flow diagram in Figure 3.3.

Shipment Release Strategy

1. No consolidation : 0 day holding time
2. 1 day consolidation : 1 day holding time
3. 3 day consolidation : 3 days holding time
4. 7 day consolidation : 7 days holding time

Location Strategy

Heuristic selection of location of consolidation center

Variables Considered

A. Dependent Variables

1. Total Procurement Cost per cwt.
2. Mean transit Time
3. Transit Time Standard Deviation

B. Independent Variables

1. Order Size Factor(LFACTR)
2. Concentration of Vendors in a region, simulated by
Order Number Factor(OFACTR)
3. Number of Consolidation Centers(NCNTR)
4. Consolidation Center Boundary(MAXD)
5. Line-haul Distance between consolidation center
and Destination(LHD)

Figure 3.2. Study Structure

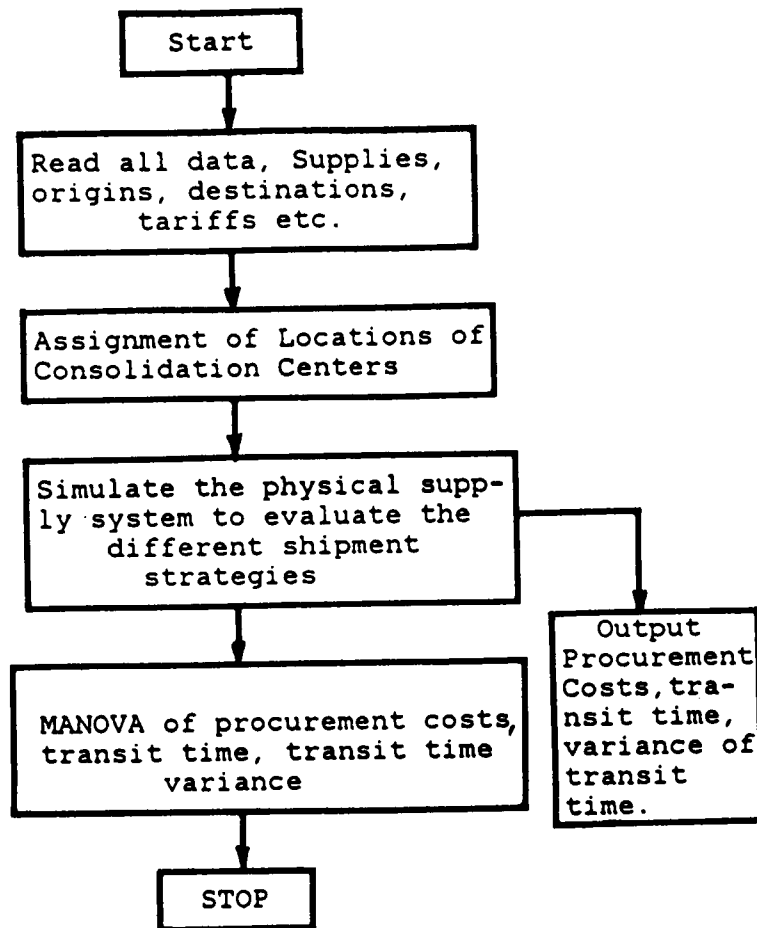


Figure 3.3. Flow Diagram for the Research Plan

3.4 VARIABLES

3.4.1 Dependent Variables

The dependent variables considered in this study were the following:

1. total procurement cost per hundred weight,
2. mean time in system, also referred to as delivery time elsewhere in this study, and
3. delivery time standard deviation.

The above-mentioned dependent variables were collected for various shipment structures and different combinations of demand and location characteristics as given by the various combinations of the independent (predictor) variables given in the next paragraph. Total cost per hundredweight was chosen as the measure because total load carried during a year varied for different values of the variables across various shipment strategies studied. Delivery time and delivery time standard deviation were used as the measures of customer service level.

3.4.2 Independent Variables

The primary predictor or independent variable in this study is the shipment structure. The structure varied, depending on whether or not consolidation is used. The levels of the consolidation structure varied based on the number of holding days at the consolidation center. If the holding

time was zero day, then orders were not consolidated, and instead they were transported directly from the source. Consolidation levels were one day, three days, five days, or seven days holding time at the consolidation center.

Demand and location variables considered in this study were: shipment size factor, concentration of suppliers measured by order number factor, number of consolidation centers, consolidation center boundary, and line-haul distance between consolidation center and the destination. Table 3.2 indicates the levels and the ranges of the independent variables.

TABLE 3.2
Independent Variables and their Levels

Variable Name	Variable Abbreviation	Levels			
		1	2	3	4
Order Size Factor	LFACTR	1.0	0.5	0.33	0.25
Concentration of Suppliers	OFACTR	1.0	2.0	3.0	4.0
Consolidation Center Boundary (Miles)	MAXD	100	150	200	
Line-haul Distance Between Consolidation Center and Destination	LHD	1300	800		
Number of Consolidation Centers	NCNTR	1	2		

Note: Locations considered for consolidation center are: Chicago, Illinois and Cincinnati, Ohio. Pure multipliers like, LFACTR and OFACTR were used to change the load generated and vendor/supplier concentration in multiples of the existing values. For example, LFACTR=1 would mean existing level of mean shipment size. Similarly, OFACTR=2 would mean a level of 200 % of the existing number of orders received per day.

3.5 SIMULATION MODEL

Building a simulation model involves the following steps:¹⁷

1. formulation of the computer model,
2. validation of the model,

¹⁷ Hillier, Frederick S., and Lieberman, Gerald S., "Introduction to Operations Research," Holden-Day, Inc., 3rd ed., 1980, pp. 647-673.

3. the experimental design for simulation, and
4. the analysis of the simulated data.

Formulation of the Computer Model

Formulation of the computer model¹⁸ comprises the following:

1. mathematical statement of the problem,
2. programming logic and language,
3. inputs required by the model, and
4. the output obtained from the model.

Mathematical Statement of the Problem

The primary aim of the model is to compare overall procurement costs between an unconsolidated LTL shipment scheme, and a number of consolidated shipment schemes over a given period of time. The following are algebraic representations of the overall procurement costs under the two schemes.

Unconsolidated LTL Shipment Scheme

$$\sum_{i=1}^n L_{i,j,k} = LT_{j,k}$$

where: $L_{i,j,k}$ = LTL costs of shipment i for destination j during time period k .

$LT_{j,k}$ = LTL costs of all shipments for destination j during time period k .

¹⁸ For a complete discussion see Pritsker, A. Alan B., "Introduction to Simulation and SLAM II," System Publishing Corporation, West Lafayette, Indiana, 1984.

Consolidated Shipment Scheme

$$\sum_{i=1}^n PU_{imk} + \sum_{i=1}^n H_{imk} + \sum_{i=1}^n I_{imk} + \sum_{i=1}^n T_{imjk} = TL_{mk}$$

where: PU_{imk} = Pick-up and delivery cost for shipment i from the source to the consolidation center m during a time period k .

H_{imk} = Handling costs for shipment i at consolidation center m during time period k .

I_{imk} = Inventory carrying costs created by holding the shipment i at consolidation center m during time period k .

T_{imjk} = Line-haul transportation costs for movement of shipment i from the consolidation center m to the destination j during time period k .

TL_{mk} = Total costs of a consolidated shipment scheme from consolidation center m during time period k .

The line-haul transportation cost from the consolidation center to the destination is one rate¹⁹ based on the total weight of the consolidated shipment, the distance moved, and the carrier. In this study, the line-haul rates used were based on a mileage rate and an average truckload shipment weight of 16,000 pounds. These rates were obtained from Midwestern Distribution Inc., a Cleveland-based line-haul carrier and a subsidiary of Leaseway Transportation, Inc. These rates and the truckload shipment weight reflects the actual rates paid by the company and the truckload

¹⁹ FAK (freight all kinds) rate which is a negotiated rate agreed upon by the purchaser and the carrier. Without loss of generality this will simplify the magnitude of the problem.

weight transported for the company.

The pick-up and delivery charge is a local transportation charge which is based on the origin and consolidation center location, the weight of the shipment, and the type of commodity carried. Class 100 rates were used in this study to reflect the actual practice followed by the company.

The handling cost at a consolidation center is based on the weight of goods handled.

Inventory carrying costs will be affected by consolidation to the extent that the shipments are held at the consolidation center. The components of inventory carrying costs²⁰ are :

1. capital costs,
2. inventory service costs,
3. storage space costs, and
4. inventory risk costs.

However, in the absence of relevant information, the inventory carrying costs have not been included while calculating the total costs. This does not seriously affect the results since the same has been excluded in both unconsolidated and consolidated shipment schemes. A list of other assumptions made for building the simulation model has been given in Appendix C.

²⁰ See Fogarty, Donald W., and Hoffman, Thomas R. in Production and Inventory Management, South-Western Publishing Co., 1983, pp. 186-188.

3.5.1 The Modeling Technique

A computer-based, event-oriented, Monte Carlo simulation model was chosen as the vehicle of research. Such a simulation model is preferable to manipulation of parameters on a real-life supply system for reasons of cost and time. The consolidation problem as seen in this study is both dynamic and stochastic. It is dynamic because we have to take into account the variable time. The importance of the time variable can be observed in terms of holding time at the consolidation center. The consolidation problem is stochastic because we have to consider variables like, transit time, order size, and frequency of supplies; each of which is stochastic in nature. Based on existing literature, a Monte Carlo simulation is preferable to deterministic analytical techniques when the physical process is both stochastic and dynamic.²¹

3.5.2 The Model

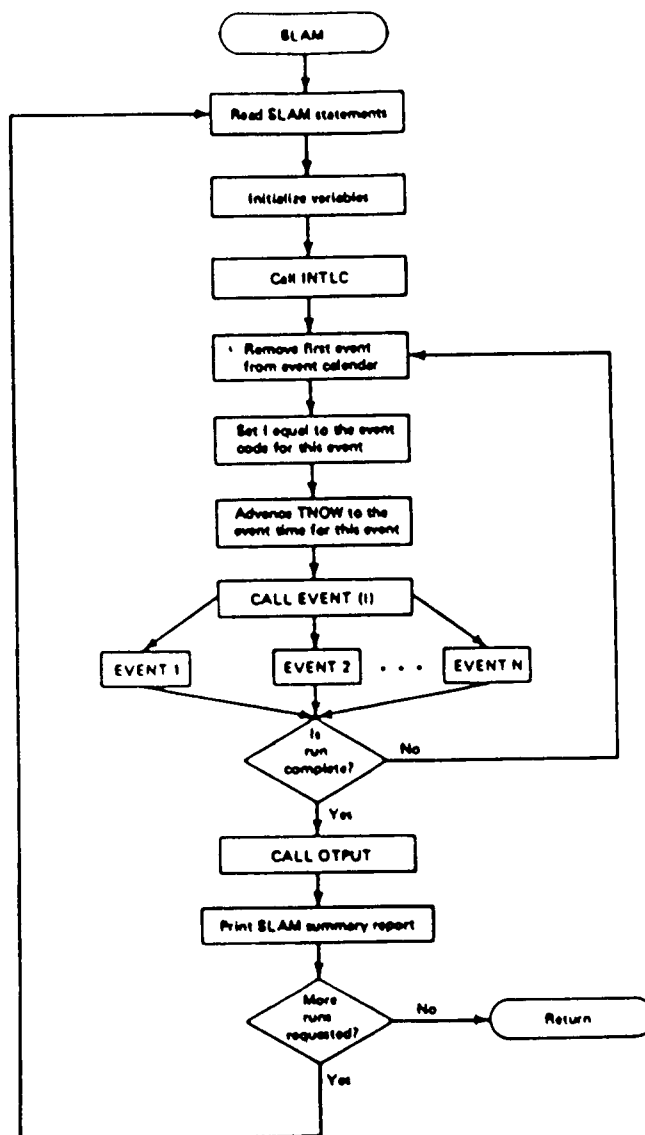
The basic simulation model will be programmed in SLAM II,²² which is a FORTRAN-based simulation language. The model is composed of these components: (1) the order generator, i.e., the shipment arrival module, (2) the decision

²¹ See Jackson, George C., in "An Experimental Investigation of the Order Consolidation System", Unpublished Ph.D dissertation, Ohio State University, Columbus, Ohio, 1980.

²² SLAM and SLAM II are registered trademarks of Pritsker & Associates, Inc.

module or the review module, (3) the shipment module, (4) the shipment receipt module, and (5) the report generator. The flow charts for the above modules have been given in Figures 3.4, 3.5, 3.6, 3.7, and 3.8.

Each simulated day, a specific number of inbound shipments are generated in the arrival module of the model. The daily number of shipments are generated from a random number generator having poisson distribution. The distribution was selected on the basis of historical data. A chi-square goodness of fit test was applied to determine the validity of this. The sources, where the shipments originate in the model, were obtained from a random number generator having a user-defined probability distribution, in which each origin zip code had the same frequency of appearance as that in the historical data. The shipment weights originating at a particular origin zip were obtained from a random number generator having uniform distribution between the minimum and maximum weights for that zip code as found in the historical data. These shipments were then assigned to a predetermined consolidation center, depending on the location of the origins of these weights. The assignment was based on the distance of the origin from the consolidation center. For each simulation run, the maximum distance of an origin, to be included in a consolidation system, was specified. This distance defined the territory to be served from a consolida-



Legend: Event 1 - Shipment Arrival, Event 2 - Review, Event 3 - Shipment, Event 4 - Receipt of Shipment, Event 5 - Report Generator.

Source: Simulation and SLAM by A. Alan B. Pritsker, Second Ed., Halstead Press, 1984, p.239.

Figure 3.4. SLAM Flow Chart

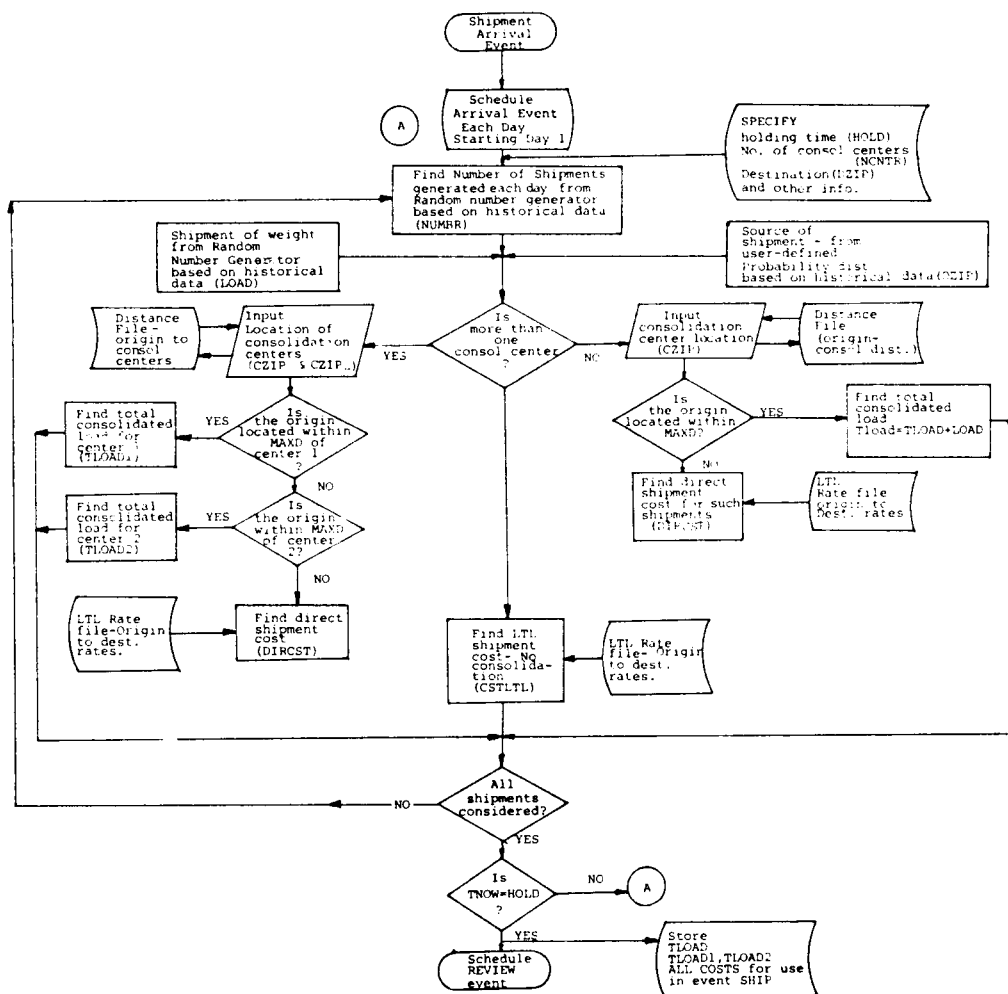


Figure 3.5. Shipment Arrival Module

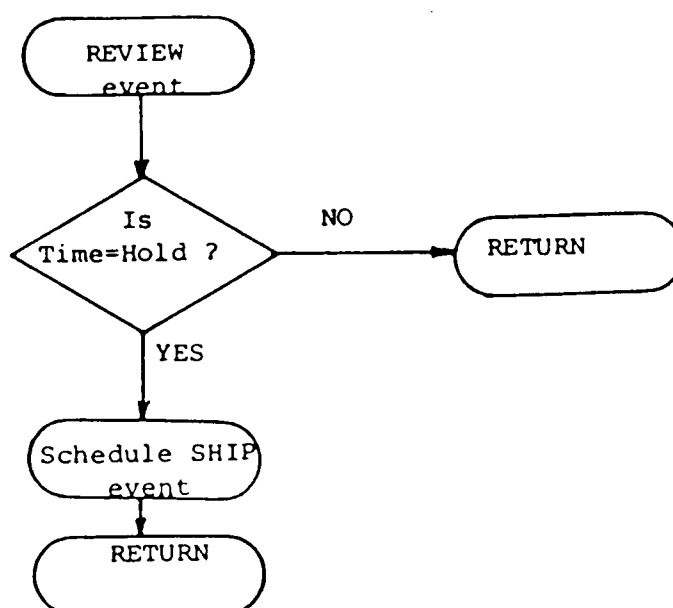


Figure 3.6. Review Module

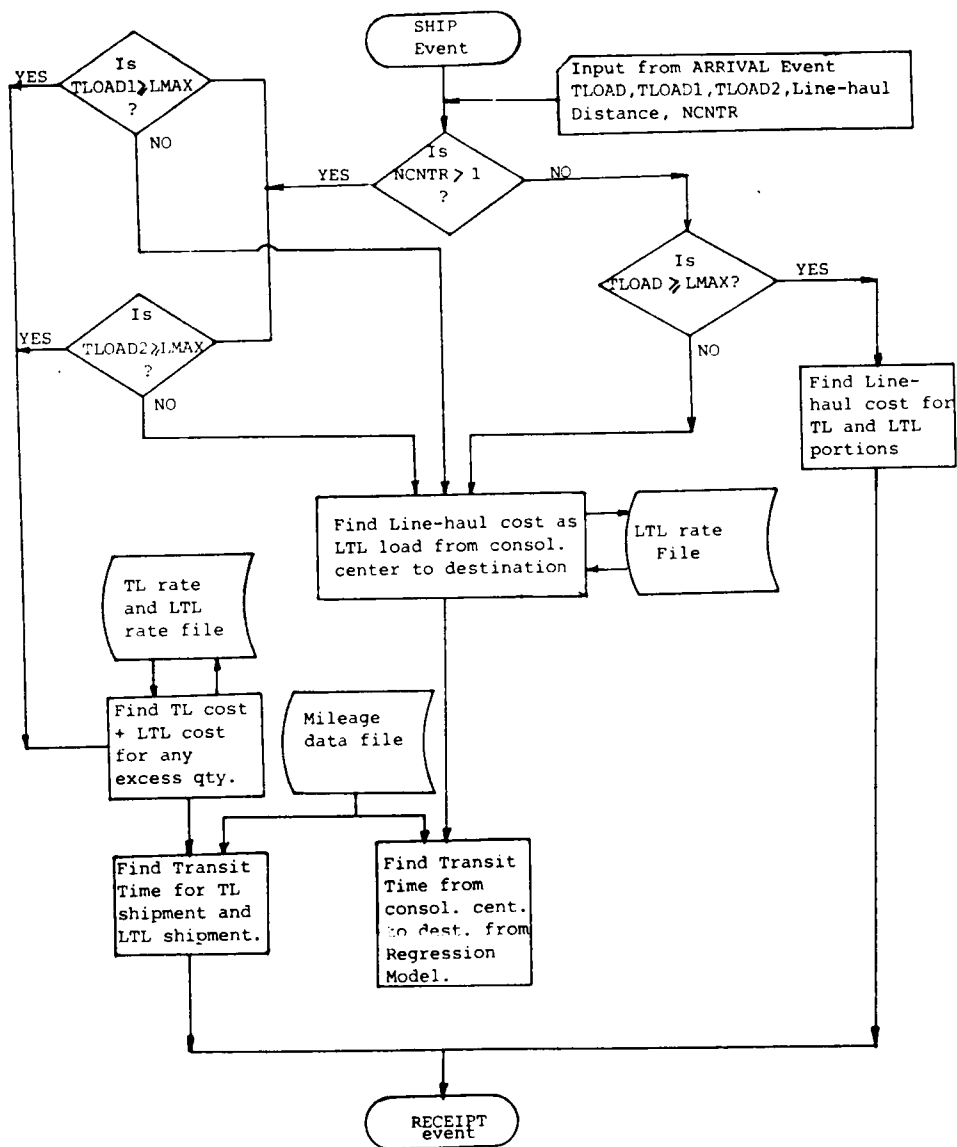


Figure 3.7. Shipment Module

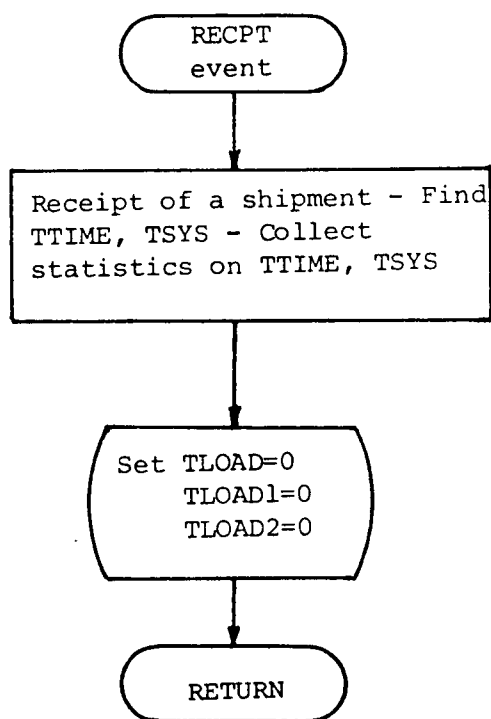


Figure 3.8. Receipt Module

tion center. Shipments not assigned to any of the consolidation centers, are shipped directly to the destination in the form of LTL loads. Each consolidation center maintains a file which lists all the loads that are waiting for dispatch to the destination. In the review module, based on the shipment dispatch strategy, it is determined whether the next event, the shipment module, would begin. For example, in a scheduled sailing strategy,²³ shipments are dispatched on predetermined dates. In a scheduled shipment strategy, which we have followed in the present study, on predetermined days module review causes the next event, the shipment module to begin.

In the shipment module, the actual shipment takes place and these shipments are taken out of the pending file for the consolidation center. On a shipping day, a total consolidated load is shipped. Transit times and transportation charges were determined in this module. Truck load transit times were calculated in days from a commercial package.²⁴ Less than truck-load transit times were obtained from a regression model, based on the actual delivery times for less than truck-load shipments, and were obtained from a national

²³ See Jackson, George C., "A Survey of Freight Consolidation Practices," *Journal of Business Logistics*, Vol.6, No.1, 1985, p.19.

²⁴ This was obtained from Logistics Resource, Inc., a subsidiary of Leaseway Transportation, Inc., Cleveland, Ohio 44122.

carrier from one of the terminals located in the midwest. Transportation charges were determined by calculating the origin-destination distance and applying the appropriate tariffs. Rates for LTL shipments were obtained from a commercial database.²⁵ Common carriage rates were used for calculating the costs of shipping into the consolidation center. The line-haul rates from the consolidation center to the destination were obtained from Midwestern Distribution, a subsidiary of Leaseway Transportation Corporation, through Logistics Resource, Inc. These rates were based on a mileage cost and best approximates the actual costs of the company whose data has been used in this study. For purposes of this study, consolidation costs were considered equal at each location, although in reality they may vary to a certain extent depending on the area and the consolidator chosen. The consolidation costs were estimated to be one dollar per hundredweight for each consolidation center.

Origin-destination distances were obtained from Rand-McNally three digit zip code mileage index. Once all the shipments due to arrive during a particular time period are processed, the same sequence of events begin for the next time period.

²⁵ LTL shipment rates were obtained from the on-line data base of Numerax, Inc., 230 W. Passaic St., Maywood, NJ 07607.

There are three outputs of the model: (1) the overall procurement cost per hundredweight, (2) the average time spent in the system (also referred to as the delivery time), and (3) the standard deviation of the time in system, (also referred to as the delivery time standard deviation). The latter two are measures of customer service. Average time in the system in this study is defined as the time from pick-up of the shipment from the supplier's premises to the time of receipt at the final destination. Time in system therefore, includes any holding time at the consolidation center.

3.5.3 Validation

Validation of the model is concerned with assuring that the simulation inputs are adequately modeled, and that the model responds to these inputs in a manner similar to the actual (real-world) problem.²⁶ In other words, validation starts with the data²⁷ obtained from the order generator. If the consolidation model is to be accurate, dependable, and worthwhile, it is important to ensure not just the average rates at which supplies originate, or the average weight

²⁶ Davis, Roscoe K., and Mckewon, Patrick G., in *Quantitative Models for Management*, Kent Publishing Company, Boston, 1984, pp. 661-662.

²⁷ For a complete discussion on validation of input data, see Solomon, Susan L., in *Simulation of Waiting-Line Systems*, Prentice-Hall, Inc., 1983, pp. 11-66.

of the supplies, but also the statistical distributions which characterize the physical supply system.

In the present study, validation of the input data consisted of three steps:

1. Studying the historical data we came up with a known statistical distribution, e.g., poisson with approximate mean value of the number of shipments originating per day and meant for a certain destination.
2. Performed Chi-square goodness of fit test between the actual data and the hypothesized data.
3. Changing the parameters of the hypothesized distribution, determined the correct parameter which gives a good fit with the actual data.

Steps 2 and 3 were carried out with the aid of a computer code known as the SIMSTAT²⁸ package, after necessary modification of the code to suit it to our purpose. The frequency of occurrence of an origin zip code was obtained from a user-defined probability function with each zip code having a probability equal to that in the historical data used in this study.

Validation of the model was also done by comparing the simulated results with available historical data of the company chosen. Another validation was done by running the

²⁸ Solomon, Susan L., in "Simulation of Waiting Line Systems," copyright 1983, p. 414, Reproduced by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ, in Appendix D.

model and analyzing the results for reasonableness. Expert opinion was sought at this stage to lend credibility to the model.

3.5.4 Experimental Design

Three major factors (independent variables) at different levels will be used to measure their effects on the dependent variables e.g., overall procurement costs, transit time, and transit time variance. The experimental design has been shown in Table 3.3. The aggregate model is a completely randomized design, where all the treatments shown in the experimental design were varied at random. The just-in-time model is a blocked factorial design. The blocks representing combinations of smaller load sizes and higher delivery frequencies.

All the dependent variables will be evaluated in each simulation run. More than one observation per cell is required to perform the MANOVA, so each simulated year is divided into two equal periods of 125 days. Other factors such as, line-haul distance between the consolidation center and the destination, consolidation center boundary were also used to study their effects on the above stated three dependent variables.

Table 3.3

Experimental Design

Holding time at consol. Center	Mean Order Weight 4 levels	Concentration of Suppliers 4 levels	Number of Consol. Center 2 levels	Line-haul distance 2 levels	Consol. Center Territory 3 levels
No consolida- tion - 0 day holding time					
1-day holding time at consol. center					
3-day holding time at consol. center					
5-day holding time at consol. center					
7-day holding time at consol. center					

3.5.5 Analysis of Data

Analysis of simulated data consisted of performing multivariate analysis of variance (MANOVA) across the different shipment alternatives. The objective of MANOVA tests were to study the relations between the dependent variables, e.g., overall procurement costs, transit time, and the variance of transit time, with the independent variables, e.g., mean shipment weight, concentration of suppliers, and the number of consolidation centers. When the null hypothesis was rejected at the level of significance, $\alpha=0.01$, we applied Duncan's multiple range test²⁹ to find out between which pair of means, significant differences exist. When comparing more than two means, a MANOVA F test tells us if the means are significantly different from each other, but it does not tell us which means differ from which other means. Multiple comparison methods (also called mean separation tests or multiple range tests) give us more detailed information about the differences among the means. Duncan's multiple range test is one of the best known multiple com-

²⁹ Briefly, Duncan's multiple range test, a posteriori technique, is a systematic procedure for comparing all possible pairs of group means. The sample is divided into like subsets where the difference in means among any two groups in a subset is not significant at some stipulated level of significance. For an in-depth discussion on Duncan's test see Hines, William W., and Montgomery, Douglas C., "Probability and Statistics in Engineering and Management Science", John Wiley & Sons, 1980, p. 341., also see Carmer, S.G. and Swanson, M.R., "Evaluation of Ten Pairwise Multiple Comparison Procedures by Monte-Carlo Methods," Journal of the American Statistical Association, 1973, pp. 66-74.

parison methods, which operates in multiple stages. Duncan's method controls the comparisonwise error rate at the chosen level of significance.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter contains the results of the study. The results presented in this section are based on the simulation model built upon a specific data set. Despite variations made in the model for studying the effects of different consolidation variables, the results still revolve round the parent data set. Therefore, conclusions drawn from these results may not be globally generalizable. First of all, we present the input data analysis. Next, the formal hypotheses tests are discussed. Thereafter, we have included a discussion on any other findings. The conclusions based on these findings are given in Chapter Five.

4.1 INPUT DATA ANALYSIS

The data included all receipts of less-than-truckload (LTL) shipments from December 1, 1983 to November 30, 1984 for a Virginia-based company. The data pertained to shipments generated in the midwestern United States and meant for five different destinations. The first step was to segregate all the shipments meant for one of the five destina-

tions. In this case, the destination chosen was Miami, Florida. Once the segregation was complete, a subset of the data was obtained. This subset included data regarding over seven hundred such shipments. The next step was to obtain the following:

1. The distribution of the number of orders originating in the region, e.g., midwest
2. Finding a probability distribution which gives the probability of appearance of all the origin zip codes in the midwest where the firm had suppliers.

The distribution of the number of orders originating in the region per day was observed to follow a poisson distribution. A chi-square goodness of fit test was performed to determine if the hypothesized probability distribution can actually represent the population distribution with reasonable accuracy. The chi-square test results shown in Table 4.1 supports this hypothesis. In other words, the data set consisting of number of orders generated per day for the particular destination follows a poisson distribution with mean daily arrival of three orders. The chi-square test was performed with the aid of a revised version of SIMSTAT³⁰ computer package.

³⁰ See Appendix C for the SIMSTAT code to do a chi-square goodness of fit test. For any further details regarding SIMSTAT code, see Solomon, Susan L., "Simulation of Waiting-Line Systems," Prentice-Hall, Inc., Englewood Cliffs, New Jersey 07632, 1983, pp. 409-447.

TABLE 4.1

Chi-square Test Results for Hypothesized Poisson
Distribution with $\mu=3.0$

CLASS	NO. OF ORDERS	OBSERVED FREQ.	RELATIVE FREQ.	EXPECTED FREQ.	CHI SQUARE
1	1.0	45.00	0.149	33.46	3.98
2	2.0	50.00	0.224	50.19	0.00
3	3.0	42.00	0.224	50.19	1.34
4	4.0	31.00	0.168	37.64	1.17
5	5.0	28.00	0.101	22.58	1.30
6	6.0	14.00	0.050	11.29	0.65
7	9999.0	14.00	0.083	18.66	1.16
TOTALS		224.00	1.000	224.00	9.60

Critical chi-square value at the .05 level of significance is 12.592 for 6 degrees of freedom. Since the observed value of chi-square is 9.60 (less than critical value), the hypothesis that the observed data set follows poisson distribution with mean, $\mu=3.0$ was accepted.

The origin zip frequency distribution was obtained from the historical data and saved in the form of a probability distribution, called user-defined probability distribution in the simulation model. Shipment weights generated at any origin zip were obtained from the historical data.

The transit times for less than truckload shipments were obtained from a simple linear regression model; with time as the dependent variable and distance traveled as the predictor. The data was obtained from the Toledo terminal of a large carrier having operations throughout the country. The data set contained 162 observations. Each observation had transit time and distance traveled for LTL freight carried by the transporter. The regression model, including related statistical information is given in Table 4.2 below. The regression model was obtained by using MINITAB³¹ statistical package.

The above results show that the regression model mentioned above was able to explain about 60 % of the total variability of transit time for less than truck-load shipments. Other factors accounting for the remaining 40 % of the variation may have been (a) route followed, (b) number of stop-offs enroute, (c) equipment reliability, and (d) seasonality. No reliable data could be obtained for these.

³¹ Minitab Statistical Package, Release 82.1, Pennsylvania State University. Further information can be obtained from Minitab, Inc., 215 Pond Laboratory, University Park, PA 16802.

TABLE 4.2

Regression Analysis for LTL Transit Time using Minitab

THE REGRESSION EQUATION IS
 $C1 = 2.47 + 0.00266 C2$

WHERE:

C1= TRANSIT TIME, DAYS

C2= DISTANCE, MILES

COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
	2.4750	0.1810	13.68
C2	0.0026631	0.0001754	15.18

S = 1.159

CO-EFFICIENT OF DETERMINATION:

R-SQUARED = 59.5 PERCENT

R-SQUARED = 59.2 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS=SS/DF
REGRESSION	1	309.69	309.69
RESIDUAL	157	210.98	1.34
TOTAL	158	520.67	
F-VALUE	309.69/1.34=231.11		

The critical F-value for one degree of freedom in the numerator and one hundred fifty seven degrees of freedom in the denominator is 6.36. Hence the null hypothesis that the correlation between the variables transit time and distance traveled is zero, is rejected at a level of significance, $\alpha=0.01$. In other words, the above ANOVA Test shows that there is a significant relation between these variables.

However, results obtained from this estimator compare favorably with the results presented by Piercy and Ballou.³² Therefore, this estimator may be considered as a fairly efficient predictor. The ANOVA test shown above, supports this contention.

The transit times for truckload dispatches were obtained from a mileage-based time calculator. The transit time for consolidated shipments were obtained from either the truckload time calculated from the mileage-based calculator or the less than truckload time obtained from the regression model, depending on the extent of the consolidated load.

4.2 HYPOTHESES TESTS

4.2.1 Cost

The results of the multi-variate analysis of variance and Duncan's multiple range tests using SAS³³ (Statistical Analysis System), based on the aggregate data set³⁴ have been given in Appendix F. Excerpts from these results have been reproduced below to aid the discussion on the tests of

³² See Piercy, James E. and Ballou, Ronald H., "A Performance Evaluation of Freight Transport Modes," The Logistics and Transportation Review, Vol. 14, No. 2, 1978, pp. 99-115.

³³ See SAS Users' Guide-Statistics, 1982 edition, SAS Institute, Inc., Box 8000, Cary, NC.

³⁴ In the aggregate data set random variation was made in all the independent (predictor) variables.

hypotheses. As will be evident from Table 4.3, the results support the following hypothesis.

TABLE 4.3

MANOVA Results with Cost per cwt as the Dependent Variable
for the Full Model

Source of Variation	Sum of Squares	Mean Squares
Model :	8,268.4535	590.60
Error :	5,117.4725	7.60
Total :	13,385.9260	
F-Value :	77.6700	
PR>F :	0.0001	
R-Square:	0.62	

The null hypothesis that unconsolidated shipments are no more expensive than consolidated shipments under various shipment strategies was rejected at the aggregate level, with a level of significance $\alpha=0.0001$. Also, 62 % of the total variability of the cost per cwt has been explained by the predictor variables. Also, Duncan's multiple range test was performed in order to evaluate the different shipment strategies. The results of Duncan's test at an $\alpha=0.01$ is given in appendix F. The results show that the mean cost per cwt for one day holding time and for unconsolidated shipment scheme are not significantly different. The mean cost per cwt for holding time of three days, five

days, and seven days are not significantly different between themselves, although these are different from either one day-consolidation or no consolidation. These results will be evident from Table 4.4 below.

TABLE 4.4

Duncan's Test Results for Cost per cwt, Alpha=0.01

Duncan Grouping	Mean cost per cwt	Number of Observations	Holding Time Days
A	25.337	136	1
A	25.268	200	0
B	22.592	114	3
B	21.986	122	7
B	21.899	116	5

Note: Means with the same letter in Duncan grouping are not significantly different. Letters 'A', 'B' etc. merely signifies different groups as measured by the dependent variable, e.g., mean cost per cwt in this case. Each observation represents a simulation run for 125 days. This is true for all other similar tables in this chapter.

Since Duncan's test only controls the type I comparisonwise error rate, we also did Tukey's studentized range test which controls the type I experimentwise error rate. The results of the Tukey's test supports the above results of Duncan's test. The results of the Tukey's test are given in Appendix F. A graph showing the relation of cost per hundredweight and holding time at the consolidation center is shown in Figure 4.1.

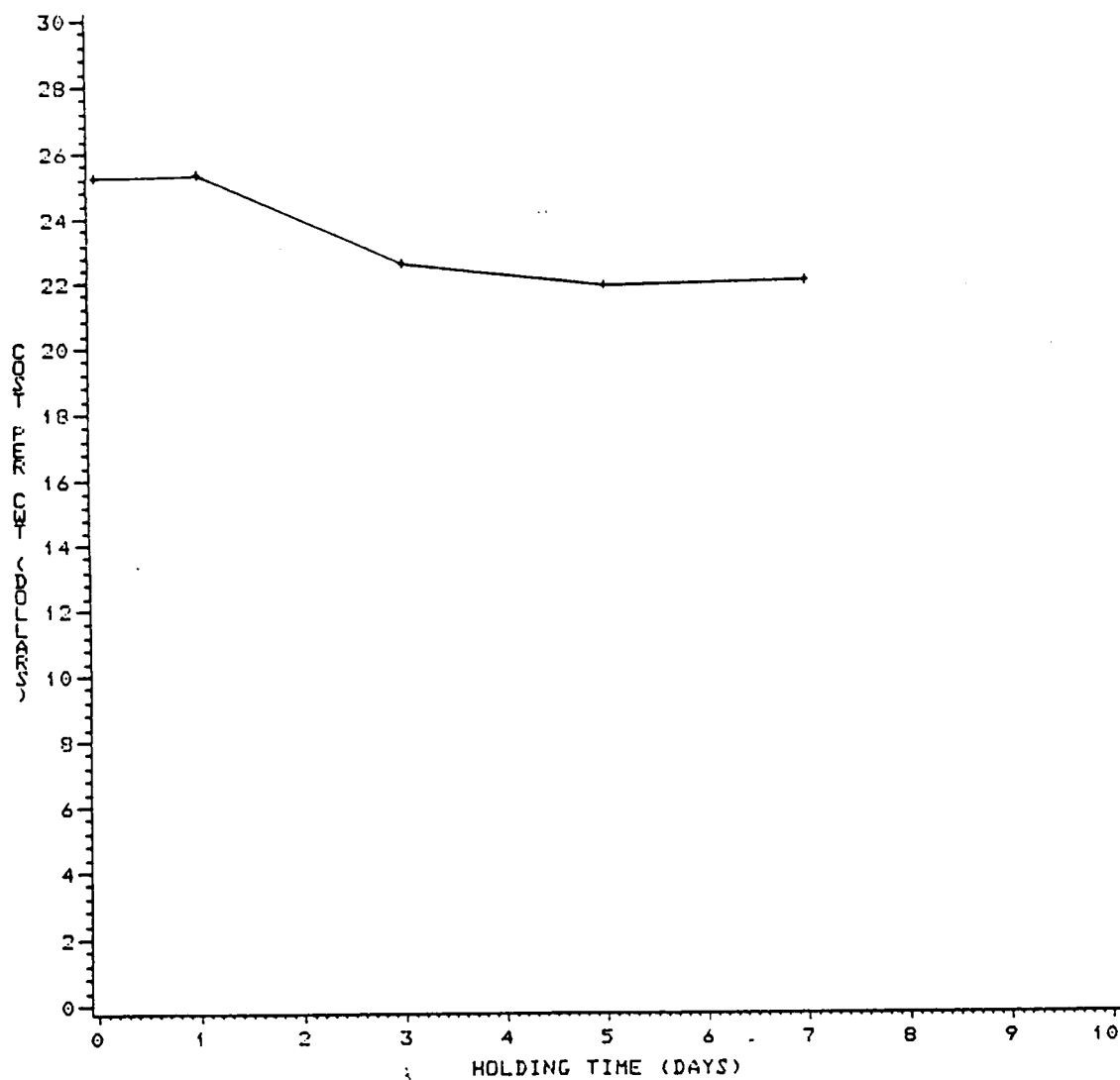


Figure 4.1. Cost per cwt Vs Holding Time

It was clear from Figure 4.1 that the cost per cwt began to decrease for holding times beyond one day, and the decrease was sharp between one-day holding time and three-day holding time. Thereafter, the rate of reduction in cost somewhat leveled off. This phenomenon of reduced slope of the cost line may have been due to a gradual reduction in the rate of increase of the proportion of truck-load dispatches. Finally, there could be a point where shipments from all vendors located within the territory are shipped as truck-loads. Duncan's multiple range test was then performed to identify the effect of the other predictor variables, e.g., load factor (LEACTR), order number factor (OFACTR), maximum distance around a consolidation center or consolidation center boundary (MAXD), line-haul distance between consolidation center and destination (LHD), and number of consolidation centers (NCNTR) on mean cost per cwt. The results of these tests bring out some interesting information. These results have been given in Appendix F. As expected, we observe that as shipment sizes reduce, cost per cwt increases, as would be evident from Table 4.5 below. Duncan's test to find significantly different mean cost due to order number factor however, was not so clear. For certain range of values of order number factor, the mean cost was not found to be significantly different. The results of the Duncan's test are given in Appendix F and also shown in Table 4.6 below.

TABLE 4.5

Duncan's Multiple Range Test for Variable Cost per cwt
(DOLRAT) at Alpha=0.01

Duncan Grouping	Mean Cost per cwt	Number of Observations	Load Factor
A	25.725	120	0.25
A	25.613	168	0.33
B	24.056	172	0.50
C	20.920	228	1.00

Note: Means with the same letter as Duncan grouping are not significantly different. Load factor is merely a multiplier to the load generated at any origin.

TABLE 4.6

Duncan's Multiple Range Test for Variable Cost per cwt
(DOLRAT) at Alpha=0.01

Duncan Grouping	Mean Cost per cwt	Number of Observations	Order Number Factor
A	25.725	120	4.0
B	24.556	160	3.0
B	23.977	180	2.0
C	22.665	32	1.5
C	21.634	196	1.0

Note: Means with the same letter as Duncan grouping are not significantly different. Order Number Factor is a multiplier to the number of orders generated on a certain day.

To further probe the effect of order numbers, a portion of the data set was separated. This data set had load factor

fixed at one, and Order number factor had values greater than one. Duncan's test was performed with the data set. The results of the Duncan's multiple range test shows that mean cost per cwt is not significantly different despite a variation of order numbers. The results of the Duncan's test are given in Table 4.7 below.

TABLE 4.7

Duncan's Multiple Range Test for Variable Cost per cwt
(DOLRAT) at Alpha=0.01

Duncan Grouping	Mean Cost per cwt	Number of Observations	Order Number Factor
A	24.718	6	1.50
A	24.559	6	1.75
A	24.476	6	2.25
A	24.433	6	1.00
A	24.401	6	1.25
A	24.282	6	2.75
A	24.221	6	2.50
A	24.205	6	3.00
A	24.110	6	2.00

Note: Means with the same letter as Duncan grouping are not significantly different. In other words, the above values of order number factors do not result in significantly different costs.

However, it was quite clear that cost per hundredweight decreases as number of orders increase and with it the percentage of shipments moved as truck-loads increases. Figure 4.2 demonstrates this.

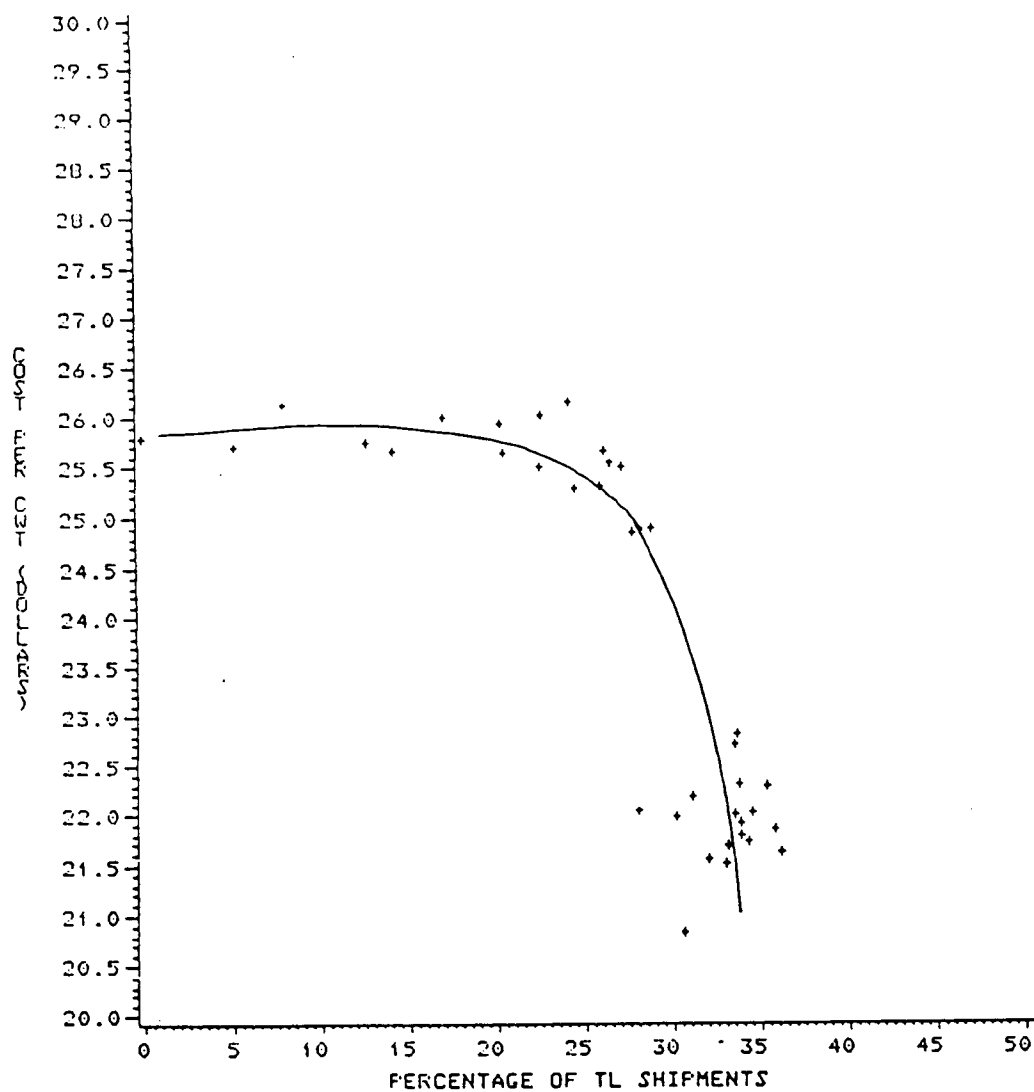


Figure 4.2. Cost per hundredweight Vs Percentage of TL Shipments

The next step was to study the effects of the consolidation center boundary (MAXD), on cost per cwt (DOLRAT). At the aggregate level, the null hypothesis that cost per cwt does not significantly vary with the boundary, was rejected at level of significance, $\alpha=0.0013$. The results of the Duncan's test, shown in the Table 4.8 below, suggests that significant differences exist in the cost per cwt when boundary was one hundred miles and that when boundary was two hundred miles.

TABLE 4.8

Duncan's Multiple Range Test for Variable Cost per cwt (DOLRAT) at $\alpha=0.01$

Duncan Grouping	Mean Cost per cwt	Number of Observations	Consol Center Boundary('00 miles)
A	24.096	290	1
A B	23.710	206	1.5
B	23.052	192	2

Note: Means with the same letter as Duncan grouping are not significantly different.

Apart from the above, the MANOVA tests on aggregate data set also rejected the null hypothesis that cost per cwt denoted by DOLRAT, does not vary with the line-haul distance between the consolidation center and the destination at level of significance, $\alpha=0.001$. The results of the Duncan's test are shown below in Table 4.9.

TABLE 4.9

Duncan's Multiple Range Test for Variable Cost per cwt at
Alpha=0.01

Duncan Grouping	Mean Cost per cwt	Number of Observations	Line-haul Distance (in '00 miles)
A	25.179	449	13
B	20.887	239	8

Note: Means with the same letter as Duncan grouping are not significantly different.

It is generally expected that cost rises with the distance traveled. To probe the effect of line-haul distance further, the effect of line-haul distance was examined on the cost per cwt per hundred miles. MANOVA results showed significant differences in the cost per cwt per hundred miles (MILRAT) depending on the line-haul distance. The MANOVA results are given in Appendix F. The MANOVA results were supported by Duncan's test also. The results of the Duncan's test are given below in Table 4.10.

However, the MANOVA tests on the aggregate data failed to reject the null hypothesis that cost per cwt does not significantly vary with the number of consolidation centers at a level of significance, $\alpha=0.01$. The results of the MANOVA test are shown in Appendix F. The results of Duncan's test, as reproduced below in Table 4.11, also failed to show any significant difference in the mean cost based on changes in the number of consolidation centers used.

TABLE 4.10

Duncan's Multiple Range Test for Variable Cost per cwt per 100 mile at Alpha=0.01

Duncan Grouping	Mean Cost/ cwt/100 miles	Number of Observations	Line-haul Distance (in '00 miles)
A	2.6109	239	8
B	1.9681	241	13

Note: Means with the same letter as Duncan grouping are not significantly different.

TABLE 4.11

Duncan's Multiple Range Test for Variable Cost per cwt as the Dependent Variable with Alpha=0.01

Duncan Grouping	Mean Cost per cwt	Number of Observations	Number of consolidation centers
A	23.956	338	1
A	23.429	350	2

Note: Means with the same letter as Duncan grouping are not significantly different.

In order to demonstrate that the above results are also true in the just-in-time inventory conditions, a subset³⁵ of the aggregate data set was created simulating the just-in-

³⁵ In this subset pairwise changes were made in load factor and order number factor. Changes made in all other independent variables were according to the experimental design given in Chapter 3.

time conditions. This subset consisted of data in which pairwise changes were made in the loads received and the number of shipments received per day. In Chapter One it was discussed that the primary effects of implementation of just-in-time inventory system on the shipments will be a drastic reduction in the shipment sizes and a steep increase in the frequency of deliveries. These effects were simulated in the model by ensuring that as load reduces, the number of shipments received per day increase, and their product remains unaltered. Load received in an incoming shipment was reduced by choosing lower values of the load factor (LFACTR) and number of incoming orders were increased by increasing the values of order number factor (OFACTR). Increased value for order number factor also simulated the condition of increased vendor concentration. The results of this test with the above defined subset have been given in Appendix F. Highlights of this test are given in Table 4.12 below.

For better understanding of the relative costs of the various shipment strategies, four sub-hypotheses were tested. In this case the following alternate hypotheses, as restated below, were accepted.

1H_{1a}: Direct unconsolidated shipment scheme, is less expensive than consolidated shipment with 1 day holding time at the consolidation center.

1H_{1b}: Direct unconsolidated shipment scheme, is more

TABLE 4.12

MANOVA Tests to Demonstrate Effects of a Just-in-time
Inventory System on Cost per cwt

Source of Variation	Sum of Squares	Mean Squares
Model	6844.0753	622.1866
Error	1308.9202	2.7968
Total	8152.9955	
F-value	222.4600	
PR>F	0.0001	
R-Square	0.8394	

expensive than consolidated shipment with 5 days holding time at the consolidation center.

$1H_{1c}$: Direct unconsolidated shipment scheme, is more expensive than consolidated shipment with 7 days holding time at the consolidation center.

In case of three-day holding time however, the following null hypothesis was accepted.

$1H_0$: Direct unconsolidated shipment scheme, is no more expensive than consolidated shipment with 3 days holding time at the consolidation center.

The above results were supported in Duncan's test also as would be evident from Table 4.13 below.

The influence of load factor on the cost was clearly shown in the MANOVA test with the just-in-time data set. As

TABLE 4.13

Duncan's Multiple Range Test for Variable Cost per cwt as the Dependent Variable with Alpha=0.01

Duncan Grouping	Mean Cost per cwt	Number of Observations	Holding Time days
A	26.968	96	1
B	22.814	96	0
B	22.814	96	3
C	21.875	96	5
C	21.760	96	7

Note: Means with the same letter as Duncan grouping are not significantly different.

would be apparent from the MANOVA results in Appendix F, load factor contributed to very very significant difference in the mean cost per cwt. This result was well supported by Duncan's test also. The results of the Duncan's test which clearly shows the significant differences in mean cost are shown below in Table 4.14. The effect of other independent variables on the cost was similar to what was observed in case of the aggregate data set.

To further study the effects of vendor concentration in a just-in-time inventory situation, two small subsets³⁶ were created with high values of order number factor.

³⁶ In these subsets load factor was fixed at a value of unity to simulate existing condition, and order number factor was assigned high values to simulate high vendor concentrations. All other independent variables, except the number of consolidation centers, were kept constant in order to separate the effects of vendor concentration.

TABLE 4.14

Duncan's Multiple Range Test for Variable Cost per cwt as the Dependent Variable with Alpha=0.01

Duncan Grouping	Mean Cost per cwt	Number of Observations	Load Factor
A	25.725	120	0.25
B	24.551	120	0.33
C	22.947	120	0.50
D	19.762	120	1.00

Note: Means with the same letter as Duncan grouping are not significantly different.

In the first subset,³⁷ moderately high values of order number factor were combined with holding times of one and three days, while all other variables were kept constant. The MANOVA tests on this data subset further demonstrated that holding time at the consolidation center contributes to significant changes in the cost. Order number factor, however, did not show significant effect on cost for range of values included in this data subset. Duncan's test supported this, as would be evident from Table 4.15.

³⁷ This subset of data was termed 'JIT subset 2' in the MANOVA test, as would be found in Appendix F.

TABLE 4.15

Duncan's Multiple Range Test for Variable Cost per cwt as the Dependent Variable with Alpha=0.01

Duncan Grouping	Mean Cost per cwt	Number of Observations	Order Number Factor
A	24.718	6	1.50
A	24.559	6	1.75
A	24.476	6	2.25
A	24.433	6	1.00
A	24.401	6	1.25
A	24.282	6	2.75
A	24.221	6	2.50
A	24.205	6	3.00
A	24.110	6	2.00

Note: Means with the same letter as Duncan grouping are not significantly different.

The second data subset³⁸ contained higher values of order number factor. The MANOVA test in this case rejected the null hypothesis that cost per hundredweight is the same irrespective of the extent of order number factor at a level of significance, $\alpha=0.03$. In other words, order number factor showed significant impact on the cost for range of values considered in this data subset. This result was supported further in the Duncan's test, as would be clear from Table 4.16 below.

³⁸ In this subset higher values of order number factors were combined with changes in the number of consolidation centers. All other variables were kept constant. The MANOVA test results on this data set appear with a heading 'JIT data subset/hi vendor concentration' in Appendix F.

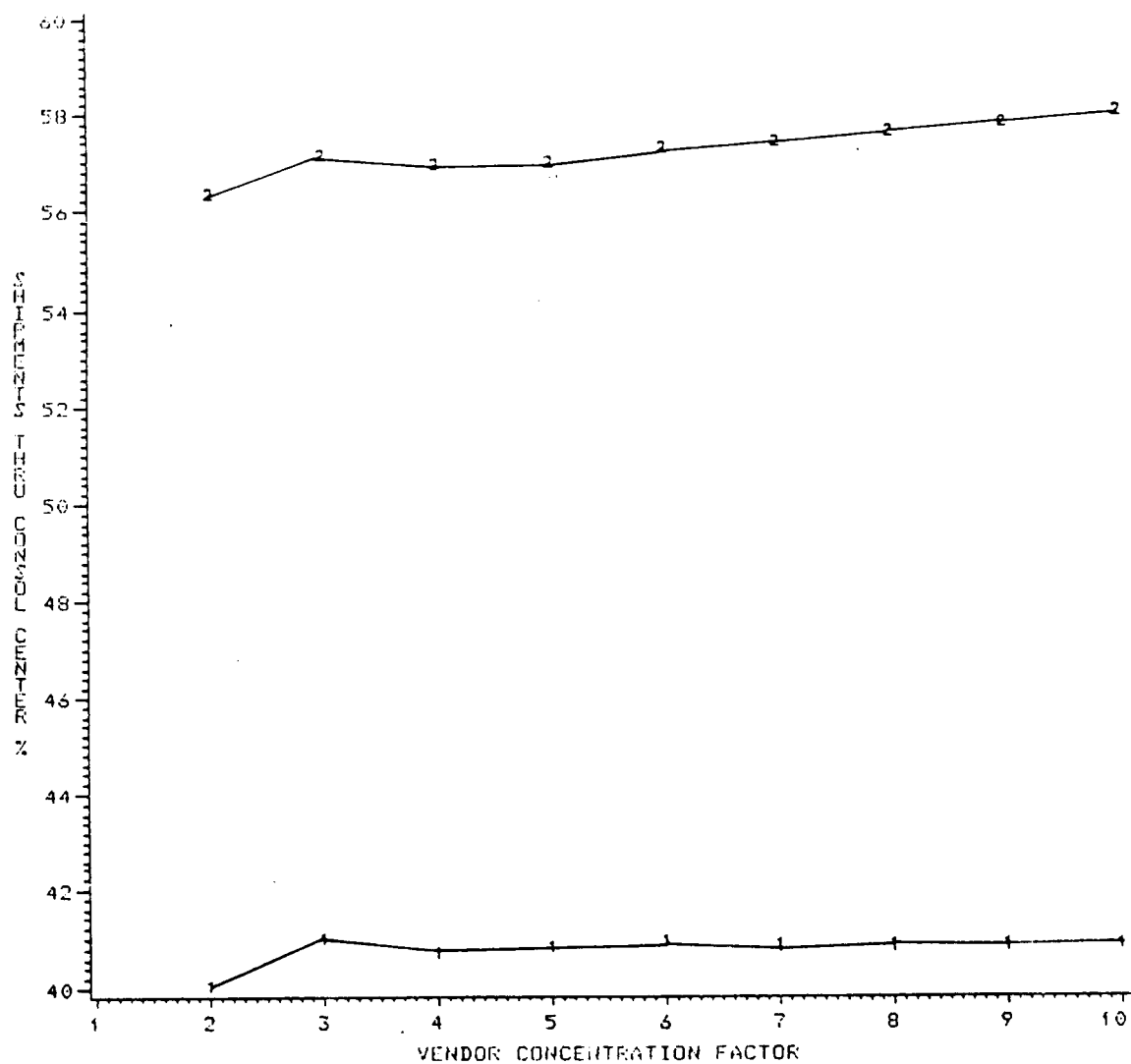
TABLE 4.16

Duncan's Multiple Range Test for Variable Cost per cwt as the Dependent Variable with Alpha=0.01

Duncan Grouping	Mean Cost per cwt	Number of Observations	Order Number Factor
A	25.742	4	2.00
A B	24.948	4	3.00
A B	24.931	4	4.00
A B	24.729	4	5.00
A B	24.542	4	6.00
A B	24.444	4	9.00
A B	24.282	4	8.00
A B	24.248	4	10.00
B	23.723	4	7.00

Note: Means with the same letter as Duncan grouping are not significantly different.

By including two consolidation centers, we were able to study the effects of percentage of shipments dispatched through consolidation centers. This variable can be expected to produce similar effect as that of vendor concentration within the boundary of a consolidation center. As would be apparent from Figure 4.3, with higher percentage of shipments dispatched through the consolidation center, as observed in a consolidated shipment scheme with two consolidation centers, the cost per cwt is lower as compared to the case of one consolidation center. It would also be clear from Figure 4.4 that, as number of orders increases, cost per cwt decreases.



1 = ONE CONSOLIDATION CENTER 2 = TWO CONSOLIDATION CENTER

Figure 4.3. Percent through Consol Center vs Vendor Concentration Factor

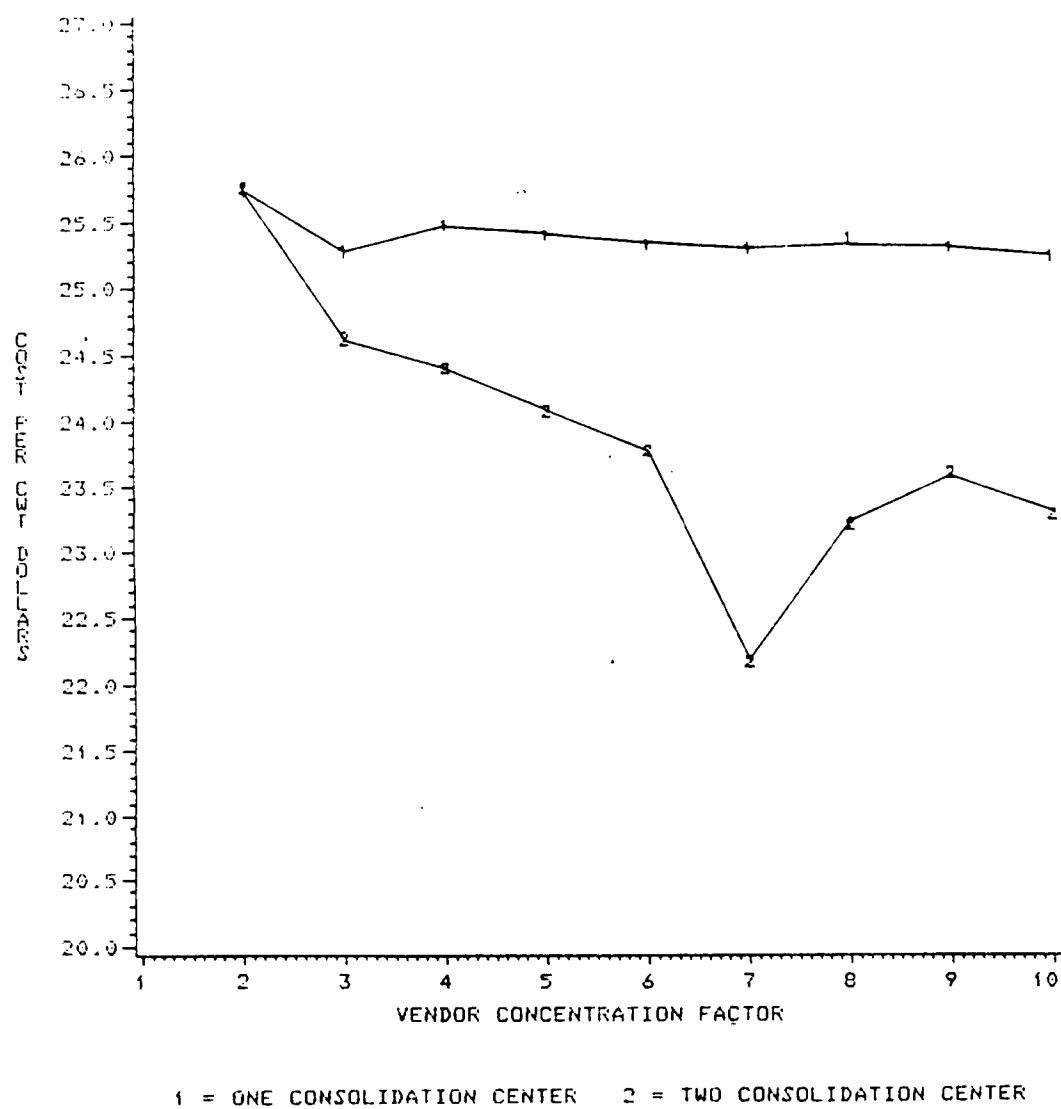


Figure 4.4. Cost per cwt Vs Vendor Concentration Factor

The results of the MANOVA test have been given in Appendix F. Next, results of MANOVA test for the customer service aspects are discussed.

4.2.2 Delivery Time

The null hypothesis of no difference of delivery time between an unconsolidated system and a consolidated system was rejected at the aggregate level at a level of significance, $\alpha=0.0001$. When the data set was classified according to holding time, and four such subsets were created, each pair comparing unconsolidated delivery time with consolidated delivery time with different values of holding time, the null hypothesis was also rejected in each case with the level of significance, $\alpha=0.001$. Duncan's multiple range test also showed significant differences in the mean delivery time at a level of significance, $\alpha=0.01$. The mean delivery time for the unconsolidated shipment strategy was higher for shipment schemes with one, three, and five days holding time at the consolidation center. However, mean unconsolidated delivery time was found to have no significant difference with that in the case of a seven day holding time at the consolidation center. The results of the above tests are given in Appendix F. Excerpts from the above tests are reproduced below in Table 4.17.

TABLE 4.17
MANOVA Tests for Delivery Time

Source of Variation	Sum of Squares	Mean Squares
Model :	280.9293	25.5390
Error :	122.0544	0.2608
Total :	402.9837	
F-Value :	97.9300	
PR>F :	0.0001	
R-Square:	0.6971	

The results of Duncan's multiple range test with delivery time as the dependent variable, and showing effects of holding time at the consolidation center are given below in Table 4.18.

TABLE 4.18
Duncan's Multiple Range Test for Variable Delivery
Time(TSYS) at Alpha=0.01

Duncan Grouping	Mean Delivery time(days)	Number of Observations	Holding Time (days)
A	8.0347	96	7
A	7.9865	96	0
B	7.0729	96	1
B	6.9764	96	5
B	6.4705	96	3

Note: Means with the same letter as Duncan grouping are not significantly different.

A graph showing the relationship between delivery time and holding time at the consolidation center is given in Figure 4.5. From the above graph it can be seen that the delivery time is significantly reduced with consolidation. Between no-consolidation and one-day consolidation there was a reduction of almost two days in the delivery time. However, with higher holding time, the delivery time increases substantially.

In the following section we have discussed the results of hypotheses tests regarding the delivery time standard deviation.

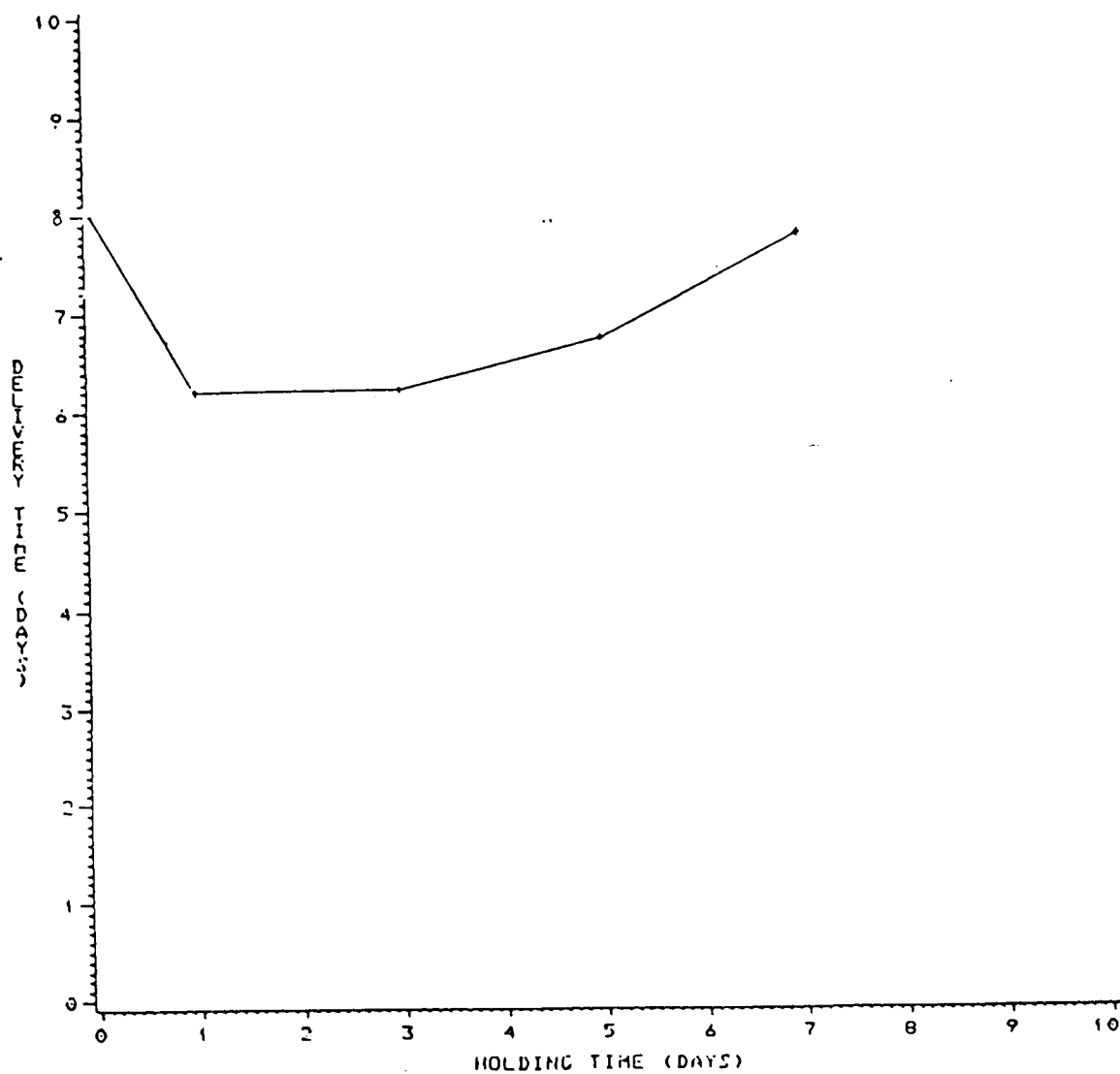


Figure 4.5. Delivery Time Vs Holding Time

4.2.3 Delivery Time Standard Deviation

The results of the MANOVA tests with delivery time standard deviation as the dependent variable are given below in Table 4.19.

TABLE 4.19

MANOVA Results with Delivery Time Standard Deviation (TSD)
as the Dependent Variable for the Full Model

Source of Variation	Sum of Squares	Mean Squares
Model :	413.1461	37.5587
Error :	69.6323	0.1487
Total :	482.7784	
F-Value :	252.4300	
PR>F :	0.0001	
R-Square:	0.8557	

The results of the MANOVA tests led to the rejection of the null hypothesis that unconsolidated shipment scheme did not differ significantly with a consolidated shipment scheme as far as delivery time standard deviation was concerned.

The results of Duncan's multiple range test, with delivery time standard deviation as the dependent variable, and showing the effects of holding time at the consolidation center, are given below in Table 4.20.

A graph showing the relationship between the delivery time standard deviation and the holding time at the consolidation center have been shown in Figure 4.6.

TABLE 4.20

Duncan's Multiple Range Test with Delivery Time Standard Deviation (TSD) as the Variable at Alpha=0.01

Duncan Grouping	Delivery time std.dev.(days)	Number of Observations	Holding Time (days)
A	3.0477	96	1
B	2.8507	96	3
C	1.8672	96	5
D	1.3448	96	7
E	0.7061	96	0

Note: Means with the same letter as Duncan grouping are not significantly different.

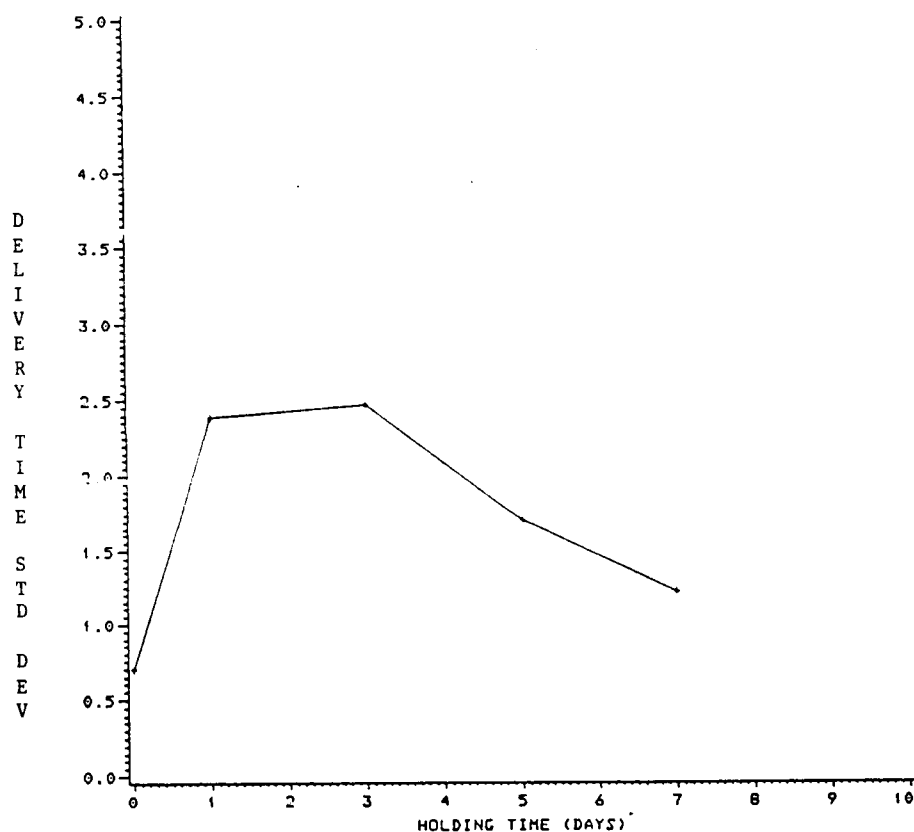


Figure 4.6. Delivery Time Standard Deviation Vs Holding Time

The results of Duncan's multiple range test showed that mean standard deviations were significantly different for different holding times at the consolidation center. The mean standard deviation of an unconsolidated shipment scheme was shown to be the least. The mean standard deviation for a seven day holding time was the least among the consolidated shipment schemes. It showed a gradual increase as holding time was reduced. As holding time increases, more consolidated loads travel as truck-loads, thereby reducing the variability to a certain extent. The reduction in the mean standard deviation of delivery time may have been the result of this phenomenon.

However, manova tests also showed that delivery time standard deviation was not significantly affected by predictors like, consolidation center boundary and number of consolidation centers used.

Likewise, the number of consolidation centers did not show any significant effect on the delivery time standard deviation. The results of the Duncan's multiple range test have been shown below in Tables 4.21 and 4.22.

TABLE 4.21

Duncan's Multiple Range Test with Delivery Time Standard Deviation(TSD) as the Variable at Alpha=0.01

Duncan Grouping	Delivery time std.dev.(days)	Number of Observations	MAXD (in '00 miles)
A	1.7921	192	2
A	1.6869	206	1.5
B	1.3977	290	1

Note: Means with the same letter as Duncan grouping are not significantly different.

TABLE 4.22

Duncan's Multiple Range Test with Delivery Time Standard Deviation(TSD) as the Variable at Alpha=0.01

Duncan Grouping	Delivery time std.dev.(days)	Number of Observations	No. of Consol Centers
A	1.6301	338	1
A	1.5598	350	2

Note: Means with the same letter as Duncan grouping are not significantly different.

4.2.4 Other Results

One not-so-apparent result, is the effect of consolidation, in general, on the number of shipments received at the final destination. It was observed that consolidation brings about a substantial reduction in the number of shipments received at the destination. Figure 4.7 shows the

percentage reduction in the number of shipments received for a holding time of one day for various values of order number factor. It is expected that, for higher holding times, as the number of truckload shipments rise, the percentage reduction will further increase.

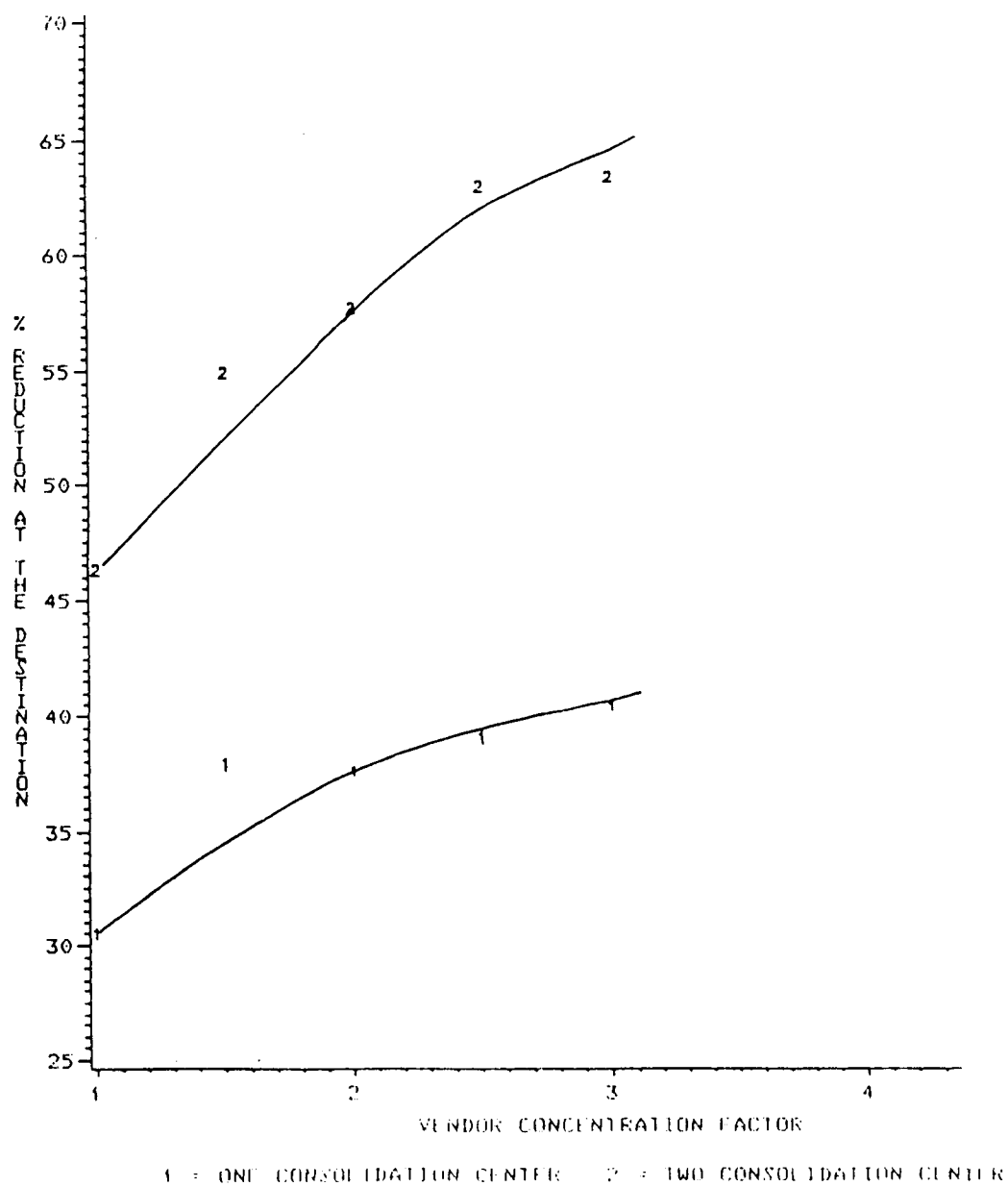


Figure 4.7. Percentage Reduction in Receipts Vs Vendor Concentration Factor

CHAPTER 5

CONCLUSIONS

This chapter consists of four sections. First, a short summary of the research project, its objectives, the hypotheses, the methodology adopted, and the conclusions based on the hypotheses tests are given. The conclusions were based on the results obtained in the previous chapter. As already pointed out, the results were based on a specific data set. Therefore, caution must be observed in making global generalization of these results. The second section contains the implications of the study in the field of logistics. The third section contains the limitations of the study. The final section contains suggestions for future research arising out of the present study.

5.1 REVIEW OF THE STUDY

Faced with mounting competition from foreign sources, the industry has been compelled to make a closer scrutiny of its procurement costs. Aided by the recent relaxation of the governmental regulations in the transportation industry, an opportunity has come up to design more imaginative and

cost-effective transportation strategies for procurement of inbound materials without sacrificing service levels. Such a strategy should naturally be justifiable in a just-in-time inventory system. One likely strategy was the consolidation of inbound freight. This research sought to compare the consolidation strategy with the existing strategy of direct shipments from vendors and also wanted to focus on the important considerations in freight consolidation. Additionally, this research sought to consider the workability of such a strategy under just-in-time inventory system.

The objectives of the research were to compare the effects of various shipment alternatives on consolidated and unconsolidated shipment schemes, and to locate the role of various factors for the management of a consolidation scheme, especially under just-in-time conditions. It was also the objective to test whether the results of the previous consolidation research on the outbound side of logistics, could be used for inbound freight consolidation also.

Based on the above objectives, a comparison was made between a consolidated system and an unconsolidated system across procurement costs, delivery time and delivery time standard deviation. The comparison revolved round a specific set of data for an organization. The scheduled shipment strategy, i.e., shipment at predetermined intervals, was followed throughout the study. Previous research on the

outbound side, suggested that cost would be reduced, mean delivery time would generally increase, and delivery time standard deviation would not generally increase from the direct shipment.

Another major question was whether certain combinations of shipment or location strategies would provide an attractive shipment scheme. The effect of the following factors were studied:

1. Direct shipment from vendors with no consolidation.
2. Shipment through consolidation centers with one, three, five, or seven day-consolidation under scheduled shipment strategy.
3. Use of one or more consolidation centers.
4. Line-haul distance of the destination from the consolidation center.
5. Boundary of consolidation centers.

The other area investigated was related to the consolidation parameters which assume greater importance under the just-in-time inventory system.

The methodology adopted for this study comprised the following steps:

1. Collection of all data related to inbound shipments for a Virginia-based medium sized organization, from all vendors located in the mid western United States.

2. Heuristic selection of locations of consolidation centers, based on concentration of shipment load. Two locations were considered, e.g., Chicago, Illinois and Cincinnati, Ohio.
3. An event-oriented Monte-Carlo simulation model based on the above to evaluate overall procurement costs, delivery time, and delivery time standard deviation for consolidated and unconsolidated systems across different levels of other relevant factors like, holding time, number of orders, load factor etc.
4. Multivariate analysis of variance and Duncan's multiple range tests to determine if significant differences exist between the different shipment alternatives and to find the most attractive alternative.

Having provided this short summary of the research objectives and methodology, the stage is now set for presenting the conclusions of the specific research hypotheses.

5.2 INTERPRETATION OF TEST RESULTS

A discussion of the results in this section consists of interpretation of the test results reported in Chapter Four and possible explanations thereof. As pointed out earlier, the following conclusions revolve round the specific data set considered in the study. Therefore, global generalization may not be applicable.

5.2.1 Cost

In this section we present the interpretation of the test results relating to cost. That is, this section addresses the first four research objectives set forth in Chapter One.

5.2.1.1 Effect of Shipment Strategy

The null hypotheses that cost per unit shipment weight are the same for both consolidated and unconsolidated shipment schemes were rejected in all cases tested, although unconsolidated shipment costs were not necessarily the greatest. It was consistently shown that consolidated shipment with one day holding time at the consolidation center came out to be the most expensive scheme. However, with a higher concentration of load, cost for one day consolidation was significantly reduced. Cost for three-day consolidation was found to be comparable to the cost for unconsolidated shipments. Seven-day consolidation proved to be the least expensive one, although the difference with five-day consolidation cost was rather small.

The area served by the consolidation center, however, had little impact on the cost. The cost savings on account of more consolidated shipments obtained by including more vendors in the area, might have been offset by the higher pick-up and consolidation costs.

Cost per unit shipment weight per unit distance was found dependent on the line-haul distance between the consolidation center and destination. As the line-haul distance increased, the cost per unit weight per unit distance reduced for the levels tested. This should be an important consideration for the establishment of consolidation centers.

5.2.1.2 Effect of Mean Shipment Weight

Effect of mean shipment weight clearly demonstrated that cost reduces as the mean weight of the shipments increases. This result was consistently shown both in the aggregate data set and in the just-in-time data set.

5.2.1.3 Effect of Vendor Concentration

Vendor concentration showed less significant effect on the cost in general. However, vendor concentration specifically within the area serviced by the consolidation center as noticed in the data set with high vendor concentration, showed substantial influence on the cost. Cost decreased with the rise in vendor concentration.

With a just- in-time inventory program, when load sizes reduce, and frequency of shipments increase, for consolidation program to be successful, one day consolidations may have to be more attractive from a cost point of view. The

whole idea of a just-in-time technique being, to bring material just in time for use, holding materials at the consolidation center perhaps runs contrary to the basic motivation behind it. Our results from the just-in-time data set however, did not justify one-day consolidation from cost point of view except, in case of very high order numbers. Most probably, the load pattern, both the extent and the concentration of vendors were not high enough to justify one-day consolidation. This poses a very important point for the implementation of a working just-in time inventory program. Before the installation of a consolidation program in a just-in-time inventory system, a thorough analysis of the load pattern would be essential. In cases of insufficient load, perhaps a stand-alone system may not be the judicious alternative. Instead, utilization of a consolidator, who could manage the consolidation program for a few other similar customers, could be a more prudent step. This was amply demonstrated by the fact that cost per unit weight begins to reduce as percentage of truckload shipments increases as a result of high vendor concentrations, and also by the fact that cost reduction was noticed only with very large number of orders.

5.2.1.4 Effect of Number of Consolidation Centers

The number of consolidation centers, however, showed no effect on the cost per unit weight. Whether there was one consolidation center in the system or more, had little impact on the cost. This was somewhat contrary to what is generally believed. By including more consolidation centers more vendors may be included in the consolidation system. This is likely to generate more consolidated load and thereby lead to less cost. It did not turn out that way in the study. Perhaps, the load pattern, especially the concentration of vendors, did not justify more than one consolidation center. However, with large number of orders in the just-in-time data subset, number of consolidation centers did produce the desired effect on cost. That is, cost per hundredweight showed significant reduction with more than one consolidation center. It was also shown that more shipments passing through consolidation center, as was the case with two consolidation centers, gave rise to a reduction in cost. This observation, perhaps, supports our earlier conclusion that in a just-in-time system, vendor and/or load concentration within the area serviced by the consolidation center, is one of the most important determinants to be analyzed before installing a consolidation program.

5.2.2 Customer Service Aspects

In this section, the interpretation of the test results relating to the customer service aspects, i.e., delivery time and delivery time standard deviation have been presented in two separate subsections.

5.2.2.1 Delivery Time

The null hypothesis that consolidated and unconsolidated shipments involve the same amount of time, was rejected at level of significance, $\alpha=0.0001$ for variables like holding time at the consolidation center and line-haul distance between the consolidation center and the destination. The same null hypothesis was rejected at a level of significance, $\alpha=0.04$ when the independent variables were shipment weight and concentration of vendors, and at $\alpha=0.06$ and 0.10 for the independent variables, consolidation center boundary and number of consolidation centers respectively. The result of these tests showed that overall delivery time reduced for one-day, three-day, and five-day consolidation schemes; while there was no significant difference in delivery between unconsolidated and seven-day consolidation scheme. It was interesting to note that delivery time in a three-day consolidation was lower than that in a one-day consolidation despite having two days of extra holding time. A larger number of full truckload shipments taking less time

in a three-day consolidation might have completely offset the extra holding time. The same observation was not true however, between five-day consolidation and seven-day consolidation or between three-day and five-day consolidation.

Shipment sizes were found to have little impact on the overall delivery time, except when the load factor became too small, e.g., LFACTR=0.25. Apparently, this runs contrary to the general belief. That is, as shipment size increases, the extent of a consolidated load also increases and more shipments could go as truckloads, thereby reducing the delivery time. However, in this study, in the aggregate data set shipment size increases were in most cases matched with proportionate reduction in the order numbers. Thus, total load generated during a period of time did not rise and perhaps that is why the delivery time did not show the likely impact. This view was further strengthened when it was observed that delivery time was not at all affected by shipment sizes in a subset of data created to simulate the just-in-time conditions by reducing load factor with matched increases in the order numbers.

Delivery time also did not show any effect of the consolidation center boundary. Expected reduction in delivery time, if any, due to inclusion of more vendors in the territory of a consolidation center and thus probably generating more truckload shipments, might have been completely offset

by the increased pick-up time for the more distant vendor locations.

Finally, it was shown that delivery time was not influenced at all by the number of consolidation centers in the system. This may have been due to the reason that available load pattern and/or concentration of vendors did not justify more consolidation centers.

5.2.2.2 Delivery Time Standard Deviation

The null hypothesis of no difference in delivery time standard deviation between unconsolidated and consolidated dispatch schemes was rejected at $\alpha=0.0001$, for the independent variables, holding time at consolidation center, mean shipment weight, and/or concentration of vendors, and line-haul distance between consolidation center and destination. Delivery time standard deviation was the least in the case of unconsolidated shipments. Among the different consolidated shipment schemes, delivery time standard deviation tended to decrease as holding time at the consolidation center increased. With lower holding time, the proportion of full truck-load dispatches diminished and this may have adversely affected the delivery time standard deviation. This should be a very important consideration in installing consolidation as a viable proposition in a just-in-time inventory program. In a just-in-time inventory program, one has

to work with reduced or ideally, zero buffer stocks. Consistency of delivery is of utmost importance. Any shipment schemes that contribute to the increase of delivery time standard deviation would not likely be an attractive proposal. For example, in cases where load pattern does not justify a majority of volume load dispatches from the consolidation center, a stand-alone consolidation program to achieve just-in-time benefits may not be justified. The extent of the differences in delivery time standard deviation due to shipment weights and concentration of vendors were very very marginal. Line-haul distance, however, made significant differences in the delivery time standard deviation. As line-haul distance increased, the standard deviation increased. This is in conformity with the findings of Piercy³⁹ and Ballou, who in a performance evaluation study of over 17,000 military and industrial shipments showed that the variability of transit time increases with the distance traveled.

However, the null hypotheses of no difference in delivery time standard deviation was not rejected for independent variables like consolidation center boundary and number of consolidation centers in the system. Also Duncan's test did not show any significant difference in the standard deviation.

³⁹ Piercy, James E., and Ballou, Ronald H., "A Performance Evaluation of Freight Transport Modes," *The Logistics and Transportation Review*, Vol.14, No.2, pp.99-115.

tion based on the consolidation center boundary and the number of consolidation centers. Again, this may have been due to insufficient available load. In a system where there could be enough load for both the consolidation centers, in their respective territories, so as to greatly enhance the proportion of full truck-load dispatches, more consolidation centers may reduce the delivery time standard deviation.

5.3 IMPLICATIONS OF THE RESEARCH

The primary objective of this research was to study the effectiveness of a consolidation program as a stand-alone system from the receivers' point of view, especially within a just-in-time inventory concept. As would be evident, the stress was on merging consolidation with the inbound material procurement system, and thus extend the freight consolidation literature.

The second objective was to explore the effects of various factors like consolidation center boundary, shipment weight, concentration of vendors, and line-haul distance, on the working of a consolidation program. These factors were not explicitly considered in earlier studies. Also, the effects of a just-in-time inventory system on a consolidation program was assessed to highlight some important considerations.

5.3.1 Cost and Customer Service

In the absence of customer service constraints, consolidation of inbound freight with three or more days holding time proved to be less expensive. Direct shipments from vendors were almost always more expensive and resulted in longer delivery times in general. The exception was consolidation with seven days holding time, in which case the delivery time was slightly more than a direct shipment from the vendors. Delivery time standard deviation, however, in general, increased in a consolidated shipment scheme. The more the holding time, the less the delivery time standard deviation. The lowest delivery time standard deviation was when holding time was seven days. However, even this was slightly higher than the delivery time standard deviation in the case of direct shipments from vendors. In essence, the lowest cost shipment scheme was not necessarily the one resulting in the least delivery time, or the minimum delivery time standard deviation. Direct shipments from vendors almost always involved maximum shipment cost, maximum delivery time and least delivery time standard deviation. This is in line with Masters'⁴⁰ conclusion that the configuration which minimized cost was not the one which resulted in the shortest delivery time or the least delivery time variance.

⁴⁰ Masters, James M., "The Effects of Freight Consolidation on Transportation and Delivery Times in a Physical Distribution System", Ph.D dissertation (Unpublished), Ohio State University, 1979.

5.3.2 Consolidation in Just-in-time Inventory System

In a just-in-time inventory program, when shipment sizes are likely to decrease and the frequency of shipment likely to increase, thereby probably necessitating daily shipments, it was observed that a minimum total mean weight was necessary to justify a consolidation program. Any stand-alone consolidation program would most likely be required to have that minimum load available in order to have a cost-effective consolidation program. This point may need to be thoroughly investigated in each individual case before establishment of a consolidation program in an organization. Organizations failing to meet this load stipulation may do well to entrust the consolidation program to an outside consolidator, who may be interested in setting up such programs for a number of organizations.

5.3.3 Effect of Other Factors

The other objective was to study the effects of other consolidation variables like mean shipment weight, concentration of vendors, consolidation center territory, number of consolidation centers, and line-haul distance moved between the consolidation center and the destination. Cost per hundredweight decreased with the increase of the mean shipment weight and the concentration of suppliers. The additional volume so generated, perhaps helps in obtaining

more truckload/volume shipments. Consolidation boundary or number of consolidation centers, however, had hardly any impact on the cost per hundredweight except, with very high volume of orders. On the contrary, line-haul distance had a significant effect on the cost per hundredweight per hundred miles traveled.

From the practitioners' or the managers' perspective, this study might be able to provide a framework for consideration of various factors before the actual launching of a consolidation program. Although consolidation may be able to reduce the costs in general, with a few exceptions, some trade-off may be necessary on the customer service aspects. Perhaps, that is how the results of this research interface with managements' decision-making function.

One of the less tangible benefits of consolidation, as noticed from this study, is perhaps, the possibility of a drastic reduction in the number of shipments to be received at the destination. This may considerably reduce the order handling costs at the destination.

5.4 LIMITATIONS OF THIS STUDY

The results of the study are limited to a certain extent primarily because of the test environment. The use of simulation instead of studying real systems may raise several questions of appropriateness of the results. In a con-

solidation problem, which is both dynamic and stochastic, simulation is preferable to a study of real-life systems for reasons of cost and time.⁴¹ Also, once a simulation model is built, it can be used repeatedly to analyze various aspects of a consolidation system. Validity of simulation is evaluated against actual performance data. Another validation is done by comparing the model formulation with other consolidation model formulations. The model in this research uses similar assumptions and methodology as those of Cooper(1984), House(1979), and Jackson(1980).

The study is also limited to a certain extent since the shipment data used was obtained from a particular firm. Another firm may or may not follow the same type of load distribution. Therefore, the results of this study can only be generalized to specific firms having the same type of load distribution. This need not be seen as a serious shortcoming, since a similar study can be easily done for another type of firm with very few changes in the computer coding.

Furthermore, in evaluating the procurement cost under different shipment alternatives, an important element, the cost of carrying inventory, was not considered for want of reliable data for the highly heterogeneous group of items

⁴¹ See Jackson, George C., in unpublished Ph.D dissertation on "An Experimental Investigation of the Order Consolidation System", Ohio State University, Columbus, Ohio, 1980 for a complete discussion on the applicability of simulation in a freight consolidation problem.

considered. As a consequence, the test results may seem to be less reliable. However, a major portion of this weakness can be adequately compensated by a judicious interpretation of the results of delivery time and delivery reliability comparisons.

5.5 SUGGESTIONS FOR FUTURE RESEARCH

This study leads to some new facets of freight consolidation which need further investigation. In the following paragraphs some suggestions are made for future research.

1. Similar investigation with different load distribution and perhaps, for different type of organizations dealing with different classes of commodities.
2. Investigation of the possibilities of using similar models as operational decision making tools. For example, by incorporating in the models ways to handle rush orders.
3. Investigation into the possibility of integrating the vendors' distribution strategy with the organizations' procurement strategy. In other words, explore the possibilities of working with the vendors to reduce shipment size and increase shipment frequency.
4. Investigation of other methods for the selection of consolidation centers. Concentration of demand was used as the heuristic in this study. In particular,

can we revise the heuristic by using a combination of demand and line-haul distance as the criterion for selection for better results? Can there be any other heuristics?

5. Determination of a break-even point value for the product of load factor and order number factor, above which consolidation would be more economical with one day holding time, thus providing a possible answer to the just-in-time inventory system.
6. Integration of inbound consolidation systems with an outbound consolidation systems. This could be possible due to the availability of advanced information systems in today's logistics systems. This could be a smart way to negotiate empty back-hauls.

BIBLIOGRAPHY

BIBLIOGRAPHY

- Akinc, Umit, and Khumawala, Basheer M., "An Efficient Branch and Bound Algorithm for the Capacitated Warehouse Location Problem, " *Management Science*, Vol. 23, No. 6, February 1977, pp. 585-594.
- Aljian's Purchasing Handbook, Fourth edition, McGraw Hill Book Company, 1982, pp. 23-2.
- Balinski, M.L., "On Finding Integer Solutions to Linear Programs, " *Mathematica*, Princeton, N.J., May 1964.
- Ballou, Ronald H., "An Extended Distribution Analysis To Support Marketing And Production Planning," *Journal of Business Logistics*, Vol. 1, No. 1, Spring 1978, pp. 63-76.
- Banks, Jerry and Carson, John S., *Discrete-Event System Simulation*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey 07632.
- Baumol, W.J., and Vinod, H.D., "An Inventory Theoretic Model of Freight Transport Demand, " *Management Science*, Vol. 16, No. 7, March 1970, pp. 413-421.
- Baumol, William J., and Wolfe, Philip, "A Warehouse-Location Problem, " *Operations Research*, Vol. 6, No. 2, March-April, 1958, pp. 252-263.
- Benders, J.F., "Partitioning Procedures for Solving Mixed-Variables Programming Problems, " *Numerische Mathematik*, Vol. 4(1962), pp. 238-252.
- Bradley, Gordon H., Brown, Gerald C., and Graves, Glen W., "Design and Implementation of Large Scale Primal Transshipment Algorithms, " *Management Science*, vol. 24, no. 1, September 1977, pp. 1-34.
- Brennan, Joseph J., "Models and Analysis of Temporal Consolidation," Ph.D dissertation, University of California, Los Angeles, 1981.

- Carmer, S.G. and Swanson, M.R., "Evaluation of Ten Pairwise Multiple Comparison Procedures by Monte-Carlo Methods," Journal of the American Statistical Association, 1973, pp. 66-74.
- Chentnik, C.G., "Fixed Facility Location Techniques," International Journal of Physical Distribution, Vol. 4, No. 1, (1980), pp. 16-25.
- Cooper, Martha C., "Freight Consolidation and Warehouse Location Strategies in Physical Distribution Systems," Journal of Business Logistics, Vol. 4, No. 2(1983), pp. 53-74.
- Efroymsen, M.A., and Ray, T.L., "A Branch-Bound Algorithm for Plant Location," Operations Research, Vol. 14, No. 3, pp.
- Feldman, E., Lehrer, F.A., and Ray, T.L., "Warehouse Location Under Continuous Economies of Scale," Management Science, Vol. 12, No. 9, May 1966, pp. 670-84.
- Geoffrion, Arthur M. and Graves, Glenn W., "Multicommodity Distribution System by Benders Decomposition," Management Science, vol. 20, no. 5, January 1974, pp. 822-844.
- Geoffrion, Arthur M. and Graves, Glen W., "Strategic Distribution Systems Planning: A Status Report," Studies in Operations Management, ed. by Arnoldo C. Hax, North-Holland Publishing Company, 1978, pp. 179-204.
- Grabner, John R., "Small Shipments: A Major Transportation Challenge," Tennessee Survey of Business 5, February 1970, pp. 29-33;
- Hageman, Robert W., "Curing Small-Shipments Headaches," Distribution Worldwide, March 1972, pp. 37-38;
- Hall, Robert W., Zero Inventories, Dow Jones-Irwin, Homewood, Illinois 60430, 1983.
- Hines, William W., and Montgomery, Douglas C., Probability and Statistics in Engineering and Management Science, John Wiley & Sons, 1980, p. 341.
- House, Robert G., "A Small Scale Facility Location Model," paper presented at the TIMS/ORSA Distribution Conference, Hilton Head, South Carolina, February 1979.
- Jackson, George C., "Evaluating Order Consolidation Strategies Using Simulation," Journal of Business Logistics, Vol. 2, No. 2(1981), pp. 110-138.

- Jackson, George C., "A Survey of Freight Consolidation Practices," *Journal of Business Logistics*, Vol.6, No.1, 1985, pp. 13-34.
- Kuehn, Alfred A., and Hamburger, Michael J., "A Heuristic Program for Locating Warehouses," *Management Science*, Vol. 9, No. 4, July 1963, pp. 643-668.
- Khumawala, Basheer M., "An Efficient Branch and Bound Algorithm for the Warehouse Location Problem," *Management Science*, Vol. 18, No. 12, August 1972, pp. B718-B732.
- Lai, Andrew W.Y., "Modeling the Motor Carrier Terminal Site Selection Decision: A Study of the Economic Feasibility of Urban Consolidation Terminal Locations," Ph.D Dissertation, The Ohio State University, 1974.
- LaLonde, Bernard J., Grabner, John R., and Robeson, James F., "Integrated Physical Distribution Systems: A Management Perspective," *The International Journal of Physical Distribution*, October 1970, pp. 133-139.
- Manne, A.S., "Plant Location under Economies-of-scale: Decentralization and Computation," *Management Science*, Vol. 11, No. 2, November 1964, pp. 213-235.
- Markland, Robert E., "Analyzing Geographically Discrete Warehousing Networks By Computer Simulation," *Decision Sciences*, Vol. 4(1973), pp. 216-236.
- Masters, James M., "The Effects of Freight Consolidation on Customer Service," *Journal of Business Logistics*, Vol. 2, No. 1(1980), pp. 55-74.
- Newbourne, M.J., *A Guide to Freight Consolidation for Shippers*, Traffic Service Corporation, Washington, D.C., 20005, second printing 1980.
- Piercy, James E., and Ballou, Ronald H., "A Performance Evaluation of Freight Transport Modes," *The Logistics and Transportation Review*, Vol.14, No.2, pp.99-115.
- Pritsker, A.Alan B., *Introduction to Simulation and SLAM II*, System Publishing Corporation, West Lafayette, Indiana, 1984.
- Reiter, S., and Sherman, G.R., "Allocating Indivisible Resources Affording External Economies or Diseconomies," *International Economic Review*, January 1962.

- Schuldenfrei, Robert L., and Shapiro, Jon M., "Inbound Collection of Goods: The Reverse Distribution Problem," *Interfaces*, Vol. 10, No. 4, August 1980, pp. 30-33.
- Schuster, Alan D., "Shipment Consolidation: The Motor Carrier's Viewpoint," *Applied Distribution Research*, ed. by Robert G. House and James F. Robeson, Transportation and Logistics Fund, The Ohio State University, Columbus, Ohio, 1977, pp. 17-21.
- Schuster, Alan D., "An Econometric Analysis of Motor Carrier LessThan-Truckload Services," Ph.D dissertation, The Ohio State University, 1977.
- Shycon, Harvey N., and Maffei, Richard B., "Simulation - Tool for Better Distribution," *Harvard Business Review*, Vol. 38, No. 6, November-December, 1960, pp. 65-75.
- Solomon, Susan L., *Simulation of Waiting-Line Systems*, Prentice-Hall, Inc., 1983, pp. 11-66.
- Sweeney, Dennis J., and Tatham, Ronald L., "An Improved Long-run Model for Multiple Warehouse Location," *Management Science*, Vol. 22, No. 7, March 1976, pp. 748-758.
- Traffic Management, "A Challenge Managers Can't Ignore," May 1984, pp. 81-82.
- Traffic Management, "Air Consolidation Vs. Surface: balanced choice aids inbound control," April 1979, pp. 85-87.
- Trill, Gilbert P., and Porter, Robert W., "How Important is Freight in Transportation," *Purchasing*, April 14, 1983, p. 43.
- _____, "Profiting from the New Freedom in Freight," *Purchasing*, April 14, 1983, p. 53.
- _____, "A Look at the Future in Inbound Freight," *Purchasing*, April 14, 1983, p. 61.
- Vollmann, Thomas E., Berry, William L., and Whybark, D. Clay, *Manufacturing Planning and Control Systems*, Richard D. Irwin, Inc., 1984.
- Wagner, Harvey M., and Whitin, T. M., "Dynamic Version of Economic Lot Size Model," *Management Science*, Vol. 5, pp. 89-96, 1958.

Weart, Walter L., "The Techniques of Freight Consolidation:
An Area of Increased Interest Aided by Computers,"
Traffic World, March 19, 1984, pp. 46-60.

Weber, Alfred, *Über den Standort der Industrien*, (Mohr,
Tübingen, 1909), translated by Carl J. Friedrich as
Alfred Weber's *Theory of Location of Industries* (Chicago:
University of Chicago Press, 1929).

APPENDICES

APPENDIX A
MATHEMATICAL FORMULATION

NOTATION:

- nc = Number of classes of items involved.
 m = Number of origins (i.e. suppliers).
 n = Number of destinations.
 p = Number of consolidation centers.
 D_{il} = Quantity of item class l ordered on origin i .
 S_l = Requirement for each item, Periodic.
 x_{ikl} = Quantity of item class l shipped from origin i to consolidation center k .
 y_{kjl} = Quantity of item class l shipped from consolidation center k to destination j .
 y_k = 1 if consolidation center k is selected, 0 otherwise.

ASSOCIATED COSTS:

- C_{ikl} = Shipping cost per unit of item l from origin i to consol. center k (LTL rate), rate can be obtained from a computer data base.
 C_{kjl} = Shipping cost per unit of item l from consolidation center k to plant j (TL rate), rate can be obtained from a computer data base.
 f_k = Variable cost per unit shipped via consolidation center k .
 F_k = Fixed operating cost for consolidation center k , if selected.
 C_k = Capacity constraint for consolidation center k .
 Z_{ki} = 1, if origin i is serviced by consolidation center k , 0 otherwise.

FORMULATION:

Minimize (Fixed cost of consolidation center + Transportation cost from origin to consolidation center + Transportation cost from consolidation center to destination + Variable cost of consolidation center including inventory carrying expenses), i.e.,

Minimize

$$\sum_{k=1}^p F_k y_k + \sum_{l=1}^{nc} \sum_{i=1}^m C_{lki} \cdot x_{lki} + \sum_{l=1}^{nc} \sum_{j=1}^n \sum_{k=1}^p C_{kjl} \cdot y_{kjl} + \sum_{l=1}^n \sum_{k=1}^p f_k \left(\sum_{i=1}^m D_{li} \cdot z_{ki} \right)$$

Subject to:

(1)... Demand constraint for each item:

$$\sum_{k=1}^b \sum_{i=1}^m x_{lki} \cdot y_k - D_{li} = 0, \text{ for } l=1,2,\dots,nc$$

(2)... Capacity Constraint for the Consolidation Center:

$$\sum_{l=1}^n \sum_{i=1}^m x_{lki} \cdot y_k \leq C_k, \text{ for } k=1,2,\dots,p$$

(3)... Material In = Material Out for each class of item and each consolidation center.

$$\sum_{i=1}^m x_{lki} = \sum_{j=1}^n y_{kjl}, \text{ for all } l \text{ and } p.$$

(4) ... $x_{lki} \geq 0$

(5) ... $y_{kjl} \geq 0$

(6) $y_k = 0 \text{ or } 1$

APPENDIX B
GEOFERRION AND GRAVES MODEL

Subscripts:

- b indexes commodity bundles for a given customer zone
- i indexes commodities
- j indexes plants
- k indexes distribution centers
- l indexes customer zones

Variables:

- v_k (v_k) the amount of underflow (overflow) of $VMIN_k$ ($VMAX_k$), at a penalty rate of PL_k (PU_k), for distribution center k.
- X_{ijk} the amount (cwt/yr) of commodity i flowing from plant j through distribution center k to customer zone l.
- Y_{klb} a binary variable indicating whether or not customer zone l is assigned to distribution center k for bundle b.
- z_k a binary variable indicating whether or not distribution center k is selected for use.

Coefficients

- C_{ijk} unit production plus transportation cost (\$/cwt) associated with the flow X_{ijk} ; equal to

$$C_{ij}^p + \begin{cases} C_{ijk}^{\text{in}} + C_{ikl}^{\text{out}} & \text{if transit does not apply} \\ C_{ijk}^t & \text{if transit applies} \end{cases}$$

where:

C_{ij}^p unit production cost

C_{ijk}^{in} unit inbound transportation and associated pipeline inventory costs

C_{ikl}^{out} unit outbound transportation and associated pipeline inventory costs

C_{ijk}^t unit transit transportation costs

F_k fixed cost (\$/yr) associated with distribution center k

V_{ik} variable throughput cost (\$/cwt) for commodity i at distribution center k

D_{i1} demand (cwt/yr) for commodity i at customer zone 1;
 $D_{i1} \geq 0$

B_i burden factor for commodity i to be used in calculating the weighted annual throughput of the distribution centers (e.g., the units of B_i would be cubic ft/cwt if weighted throughput in cube is desired)

PL_k penalty rate (\$per unit of violation) for weighted throughput less than $VMIN_k$ at distribution center k; $PL_k \geq 0$.

PU_k penalty rate (\$ per unit of violation) for weighted throughput greater than $VMAX_k$ at distribution center k; $PU_k \geq 0$.

SL_{ij} lower limit on the total shipment of commodity i by plant j (cwt/yr)

SU_{ij} upper limit on the total shipments of commodity i by plant j (cwt/yr); $SL_{ij} \leq SU_{ij}$

$VMIN_k$ lower limit on the total annual weighted throughput of distribution center k if it is open

$VMAX_k$ upper limit on the total annual weighted throughput of distribution center k if it is open;
 $VMIN_k \leq VMAX_k$.

Bundling Structure

B_l a set composed of the bundle indices defined for customer zone l (often a single commodity partition type is used for all customer zones, in which case $B_l = B$ for all l)

$I_l(b)$ a set composed of the commodity indices corresponding to bundle b for customer zone l ; thus $i \in I_l(b)$ means that commodity i is in bundle b for customer zone l ; for any given l , the set $U_{b \in B_l} I_l(b)$ consists of all commodity indices.

Optimization Problem

$$\begin{aligned} \text{Minimize} \\ v, x, y, z \quad & \sum_{i,j,k,l} \sum c_{ijkl} x_{ijkl} + \sum_k [F_k z_k + \sum_l \sum_{b \in B_l} \sum_{i \in I_l(b)} V_{ik} \\ & + \sum_k [PL_k v_k + PU_k v_k] \end{aligned} \quad (1)$$

subject to:

$$SL_{ij} \leq \sum_{kl} x_{ijkl} \leq SU_{ij} \quad \text{all } ij \quad (2)$$

$$\sum_j x_{ijkl} = D_{ij} \cdot y_{klb}, \quad \text{all } klbi \text{ such that } b \in B_l \text{ and } i \in I_l(b) \quad (3)$$

$$\sum_k y_{klb} = 1, \quad \text{all } l, b \text{ such that } b \in B_l \quad (4)$$

$$y_{klb} \leq z_k, \quad \text{all } k, l, b \text{ such that } b \in B_l \quad (5)$$

$$VMIN_k z_k - v_k \leq \sum_l \sum_{b \in B_l} \sum_{i \in I_l(b)} \beta_i D_{ij} y_{klb} \leq VMAX_k z_k \quad (6)$$

$$v_k \text{ and } v_k \geq 0 \quad \text{all } k \quad (7)$$

$$y_{klb} = 0 \text{ or } 1, \quad \text{all } k, l, b \text{ such that } b \in B_l, \quad (8)$$

$$z_k = 0 \text{ or } 1, \quad \text{all } k$$

$$x_{ijkl} \geq 0, \quad \text{all } i, j, k, l. \quad (8)$$

It is understood that all indicial summations and constraint enumerations run only over extant combinations of subscripts.

The objective function (1) is made up of three parts: a production-transportation pipeline inventory cost part, a distribution center cost part, and a throughput violation penalty part. A net sales revenue term is not included because it would just be a constant in view of the assumption that all demands must be met exactly.

Source: Geoffrion et al., "Strategic Distribution Systems Planning: A Status Report," in studies in Operations Management, ed. by Arnoldo C Hax, North-Holland, NY 1978, pp. 179-204.

APPENDIX C

SUMMARY OF ASSUMPTIONS FOR THE SIMULATION MODEL

1. The many hundreds of the inbound materials were considered similar in nature with respect to their ability to move together in a truck or trailer. In the present study this information was based on the past experience of the firm whose data was used in the study. All quantities were measured in gross shipping weight.
2. Consolidation center locations to be considered in the model were limited to a short list of locations composed of major cities in the region having high concentrations of supplies. Each candidate location had a small specific hinterland where supplies originated.
3. It was assumed that public warehouses would be utilized for consolidation centers and we did not constrain the model with capacity constraint at the consolidation center. The model will be relaxed to this extent. Without loss of generality, this will reduce the magnitude of the problem to a certain extent.
4. Historical records were utilized, wherever possible, to obtain actual transportation costs for alternative shipment schemes.
5.

The costs of each consolidation center consisted of a variable cost(\$/cwt) applied to each shipment. This cost included all pick-up, handling, storage, inventory carrying, and other operating expenses. In the present study this cost was estimated from information* available from the consolidators operating in the region under consideration.

* This information was obtained through the courtesy of Logistics Resource, Inc., a wholly owned subsidiary of Leaseway Transportation Corporation, 3700 Park East Drive, Cleveland, Ohio 44122.

APPENDIX D

FORTRAN CODE FOR CHI-SQUARE GOODNESS OF FIT TEST

```

C PROGRAM GOFFIT
C THIS PROGRAM HAS ADAPTED FROM SUSAN SOLOMON'S SIMSTAT PACKAGES.
C Tests the goodness of fit of either the negative exponential
C distribution, the poisson distribution, the normal distribution,
C the uniform distribution, or an empirically derived
C distribution. The user must provide the mean and/or standard
C deviation if appropriate as well as classes and
C class frequencies. The user may select either a chi square
C test or a Kolmogorov-Smirnov test.
REAL MEAN,II1,II2
DIMENSION WTH(100),OBSFRQ(100),ULIM(100),CCHISQ(100),CHI(25)
DIMENSION CRLFRQ(100),CTHFRQ(100),EXPFRQ(100),RELFQR(100)
DIMENSION ADIFF(100),ORLFRQ(100),XKS(35),PR(100),BOUND(100)
DATA CHI(1),CHI(2),CHI(3),CHI(4)/3.841,5.991,7.815,9.488/
DATA CHI(5),CHI(6),CHI(7),CHI(8)/11.070,12.592,14.067,15.507/
DATA CHI(9),CHI(10),CHI(11),CHI(12)/16.919,18.307,19.675,21.026/
DATA CHI(13),CHI(14),CHI(15),CHI(16)/22.362,23.685,24.996,26.296/
DATA CHI(17),CHI(18),CHI(19)/27.587,28.869,30.144/
DATA CHI(21),CHI(22),CHI(23)/32.671,33.924,35.172/
DATA CHI(24),CHI(25),CHI(20)/36.415,37.652,31.410/
DATA XKS(1),XKS(2),XKS(3),XKS(4)/.975,.842,.708,.624/
DATA XKS(6),XKS(7),XKS(8),XKS(9)/.521,.486,.457,.432/
DATA XKS(11),XKS(12),XKS(13),XKS(14)/.391,.375,.361,.349/
DATA XKS(16),XKS(17),XKS(18),XKS(19)/.328,.318,.309,.301/
DATA XKS(21),XKS(22),XKS(23),XKS(24)/.287,.281,.275,.269/
DATA XKS(26),XKS(27),XKS(28),XKS(29)/.259,.254,.250,.246/
DATA XKS(31),XKS(32),XKS(33),XKS(34)/.238,.234,.231,.227/
DATA XKS(5),XKS(10),XKS(15),XKS(20)/.565,.410,.338,.294/
DATA XKS(25),XKS(30),XKS(35)/.264,.242,.224/
1 TCHISQ=0
TOBSFR=0
TORLFR=0.
TTFRQ=0.
DIFF=0.
TEXPFR=0
TRELFQR=0
DO 3 I=1,100
WTH(I)=0.
OBSFRQ(I)=0.
ORLFRQ(I)=0.
ADIFF(I)=0.
ULIM(I)=0.
CCHISQ(I)=0.
EXPFRQ(I)=0.
CRLFRQ(I)=0.
CTHFRQ(I)=0.
BOUND(I)=0.
PR(I)=0.
3 RELFRQ(I)=0.
IOUT=6

```

```

WRITE(IOUT,2)
2  FORMAT('0Goodness of fit tests')
WRITE(IOUT,4)
4  FORMAT('0Do you want instructions?',
1' type 1 for yes, 0 for no.')
READ*, INST
IF(INST .EQ. 0)GO TO 57
WRITE(IOUT,36)
36 FORMAT('0You may choose either a chi square or a '/
1' Kolmogorov-Smirnov goodness of fit test.')
WRITE(IOUT,5)
5  FORMAT('0Which distribution do you want to test '
1/' for goodness of fit? '/' Your alternatives are:'
2/' 1. Negative exponential distribution'
3/' 2. Poisson distribution'/' 3. Normal distribution'
4/' 4. Uniform distribution'/' 5. Empirically defined '
5'distribution')
WRITE(IOUT,40)
40 FORMAT('0 ***WARNING*** Be sure that the classes you '/'
1' defined INCLUDE a mutually exclusive,collectively '/'
2' exhaustive set of possible outcomes, such as '/'
3' "plus or minus infinity", if appropriate')
57 WRITE(IOUT,6)
6  FORMAT('0Type the number of the distribution you want to test')
61 READ*, IDIST
WRITE(IOUT,7)
7  FORMAT('0You have chosen the goodness of fit test for:')
IF(IDIST .EQ. 1) WRITE(IOUT,8)
8  FORMAT(' 1. Negative Exponential Distribution.')
IF(IDIST .EQ. 2) WRITE(IOUT,9)
9  FORMAT(' 2. Poisson Distribution.')
IF(IDIST .EQ. 3)WRITE(IOUT,10)
10 FORMAT(' 3. Normal Distribution.')
IF(IDIST .EQ. 4)WRITE(IOUT,11)
11 FORMAT(' 4. Uniform Distribution.')
IF(IDIST .EQ. 5)WRITE(IOUT,12)
12 FORMAT(' 5. Empirically Defined Distribution.')
IF(IDIST .GT. 5)WRITE(IOUT,13)
13 FORMAT('0You must choose a number from 1 through 5.')
IF(IDIST .GT. 5) GO TO 61
WRITE(IOUT,38)
38 FORMAT('0If you want to do a chi square test, type a 1. '/'
1' if you want to do a Kolmogorov-Smirnov test, type a 0.')
READ*, ITEST
IF(IDIST .EQ. 1)WRITE(IOUT,16)
16 FORMAT('0Enter the mean time')
IF(IDIST .EQ. 2)WRITE(IOUT,18)
18 FORMAT('0Enter the mean rate')
IF(IDIST .EQ. 3)WRITE(IOUT,20)
20 FORMAT('0Enter the mean')
IF(IDIST .LE. 3)READ*, MEAN
IF(IDIST .EQ. 3)WRITE(IOUT,25)

```

```

25  FORMAT('0Enter the standard deviation')
    IF(IDIST .EQ. 3)READ*, STDEV
    IF(ITEST .EQ. 1)WRITE(IOUT,29)
29  FORMAT('0You have chosen a chi square test.')
    IF(ITEST .EQ. 0)WRITE(IOUT,31)
31  FORMAT('0You have chosen a Kolmogorov-Smirnov test.')
    WRITE(IOUT,30)
30  FORMAT('0Enter the number of classes')
    READ*, NCLASS
    IF(IDIST .EQ. 2) GO TO 300
    IF(IDIST .EQ. 3) GO TO 400
    IF(IDIST .EQ. 4) GO TO 500
    IF(IDIST .EQ. 5) GO TO 600
    IF(IDIST .NE. 1) GO TO 1
    WRITE(IOUT,705)
705  FORMAT('0If you want to do a goodness of fit test,',
1' type a 1.'/' If you want to compute boundaries,',
2' type a 0.')
    READ*, IPRO
    IF(IPRO .EQ. 1) GO TO 790
    XINC=1./NCLASS
    MEAN=1./MEAN
    PR(1)=XINC
    WRITE(30,710)
    WRITE(IOUT,710)
710  FORMAT('0CLASS',3X,'CUMULATIVE GT',5X,'CLASS',5X,'CLASS'/
1' IDENT',3X,'PROBABILITY',5X,'BOUNDARY',4X,'WIDTH'/)
    DO 750 IJ=1,NCLASS
    BOUND(IJ)=ALOG(PR(IJ))/(-MEAN)
750  PR(IJ+1)=PR(IJ)+XINC
    DO 760 IJ=1,NCLASS
    IF(IJ .NE. NCLASS)WTH(IJ)=BOUND(NCLASS-IJ)-BOUND(NCLASS-IJ+1)
    IF(IJ .EQ. NCLASS)WTH(IJ)=9999.99
    WRITE(IOUT,720)IJ,PR(NCLASS-IJ+1),BOUND(NCLASS-IJ+1),WTH(IJ)
    WRITE(30,720)IJ,PR(NCLASS-IJ+1),BOUND(NCLASS-IJ+1),WTH(IJ)
760  CONTINUE
720  FORMAT(1X,I5,6X,F6.4,6X,F8.2,2X,F8.2)
    WRITE(IOUT,770)
770  FORMAT('0If you want to proceed to a chi square goodness '/'
1' of fit test of this negative exponential distribution, '/'
2' type a 1. Otherwise, type a 0.')
    READ*, NEGF
    IF(NEGF .EQ. 0) GO TO 178
    IF(NEGF .EQ. 1)GO TO 55
790  WTH(NCLASS)=9999.
    NXTLST=NCLASS-1
    WRITE(30,54)
    WRITE(IOUT,54)
54  FORMAT('0','If all classes except the last are of equal width, '/'
1' enter that width.', ' Otherwise,enter 999.99')
    READ*, X
    IF(X .EQ. 999.99) GO TO 59

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```

DO 53 I=1,NXTLST
53  WTH(I)=X
55  DO 58 I=1,NCLASS
    NXTLST=NCLASS-1
    WRITE(IOUT,56)I
56  FORMAT('0Enter the observed frequency for class ',I3)
    READ*,N
    OBSFRQ(I)=N
58  TOBSFR=TOBSFR+OBSFRQ(I)
    GO TO 98
59  DO 95 I=1,NXTLST
    WRITE(IOUT,60)I
60  FORMAT('0Enter the class width for class ',I3)
    READ*, WTH(I)
    WRITE(IOUT,80)I
80  FORMAT('0Enter the observed frequency for class ',I3)
    READ*, N
    OBSFRQ(I)=N
95  TOBSFR=TOBSFR+OBSFRQ(I)
    WRITE(IOUT,96)
96  FORMAT('0','Enter **ONLY** the observed frequency,'
1'not the class width, for the last class')
    READ*, N
    OBSFRQ(NCLASS)=N
    TOBSFR=TOBSFR+OBSFRQ(NCLASS)
98  ULM(1)=WTH(1)
    IF(IPRO .EQ. 1)MEAN=1./MEAN
    EXPON1=(2.71828**(-1.*MEAN*ULM(1)))
    RELFRQ(1)=1.-EXPON1
    CRLFRQ(1)=RELFRQ(1)
    DO 100 I=2,NXTLST
    ULM(I)=ULM(I-1)+WTH(I)
    CRLFRQ(I)=1.-2.71828**(-1.*MEAN*ULM(I))
100  RELFRQ(I)=CRLFRQ(I)-CRLFRQ(I-1)
    RELFRQ(NCLASS)=2.71828**(-1.*MEAN*ULM(NXTLST))
    ULM(NCLASS)=9999
    GO TO 700
C  BEGIN POISSON CALCULATIONS
300  NXTLST=NCLASS-1
    WRITE(IOUT,303)
303  FORMAT('0 **NOTE** Only sequential integer values beginning '/
1' with zero may be used.')
    DO 320 I=1,NXTLST
    WRITE(IOUT,305)I
305  FORMAT('0Enter the class midpoint for class ',I3)
    READ*, MPT
    ULM(I)=MPT
    WRITE(IOUT,310)I
310  FORMAT('0Enter the observed frequency for class ',I3)
    READ*, OBSFRQ(I)
    TOBSFR=TOBSFR+OBSFRQ(I)
    RELFRQ(I)=MEAN**MPT*2.71828**(-MEAN)/FCTRL(MPT)

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IF(I .EQ. 1)CRLFRQ(I)=RELFRQ(I)
320 IF(I .NE. 1)CRLFRQ(I)=CRLFRQ(I-1)+RELFRQ(I)
WRITE(IOUT,330)NCLASS
330 FORMAT('0Enter **ONLY** the observed frequency for class ',I3)
READ*, OBSFRQ(NCLASS)
RELFRQ(NCLASS)=1.-CRLFRQ(NXTLST)
TOBSFR=TOBSFR+OBSFRQ(NCLASS)
ULIM(NCLASS)=9999
GO TO 700
C BEGIN NORMAL CALCULATIONS
400 NXTLST=NCLASS-1
WRITE(IOUT,405)
405 FORMAT('0Enter the upper class boundary for class 1')
READ*, ULIM(1)
WRITE(IOUT,408)
408 FORMAT('0Enter the observed frequency for class 1')
READ*, OBSFRQ(1)
TOBSFR=TOBSFR+OBSFRQ(1)
XLOW=MEAN-4.*STDEV
XHI=ULIM(1)
NN=10
P1=1./(2.*3.1415926)**(0.5)
A=(XLOW-MEAN)/STDEV
B=(XHI-MEAN)/STDEV
NN=2*NN
D=(B-A)/NN
II1=0
II2=0
II3=NN-1
DO 425 II=1,II3,2
Z=A+II*D
P=P1*2.71828**(-Z**2/2.)
II1=II1+P
Z=A+(II+1)*D
P=P1*2.71828**(-Z**2/2.)
425 II2=II2+P
ZA=P1*2.71828**(-A**2/2.)
ZB=P1*2.71828**(-B**2/2.)
S=(4./3.)*D*II1+(2./3.)*D*II2+(1./3.)*D*(ZA-ZB)
RELFRQ(1)=S
CRLFRQ(1)=RELFRQ(1)
IF(NCLASS .EQ. 2)GO TO 460
DO 450 I=2,NXTLST
WRITE(IOUT,410)I
410 FORMAT('0Enter the upper class boundary for class ',I3)
READ*, ULIM(I)
WRITE(IOUT,420)I
420 FORMAT('0Enter the observed frequency for class ',I3)
READ*, OBSFRQ(I)
TOBSFR=TOBSFR+OBSFRQ(I)
XLOW=ULIM(I-1)
XHI=ULIM(I)

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A=(XLOW-MEAN)/STDEV
B=(XHI-MEAN)/STDEV
D=(B-A)/NN
II1=0
II2=0
DO 435 II=1,II3,2
Z=A+II*D
P=P1*2.71828**(-Z**2/2.)
II1=II1+P
Z=A+(II+1)*D
P=P1*2.71828**(-Z**2/2.)
435 II2=II2+P
ZA=P1*2.71828**(-A**2/2.)
ZB=P1*2.71828**(-B**2/2.)
S=(4./3.)*D*II1+(2./3.)*D*II2+(1./3.)*D*(ZA-ZB)
RELFRQ(I)=S
450 CRLFRQ(I)=CRLFRQ(I-1)+RELFRQ(I)
460 WRITE(IOUT,470)NCLASS
470 FORMAT('0Enter ***ONLY*** the observed frequency for class ',I3)
READ*, OBSFRQ(NCLASS)
ULIM(NCLASS)=9999.
TOBSFR=TOBSFR+OBSFRQ(NCLASS)
RELFRQ(NCLASS)=1.-CRLFRQ(NXTLST)
GO TO 700

C BEGIN UNIFORM CALCULATIONS
500 DO 520 I=1,NCLASS
WRITE(IOUT,505)I
505 FORMAT('0Enter the class midpoint for class ',I3)
READ*, ULIM(I)
WRITE(IOUT,510)I
510 FORMAT('0Enter the observed frequency for class number ',I3)
READ*, OBSFRQ(I)
520 TOBSFR=TOBSFR+OBSFRQ(I)
DO 530 I=1,NCLASS
530 RELFRQ(I)=1./NCLASS
GO TO 700

C BEGIN EMPIRICAL CALCULATIONS
600 DO 630 I=1,NCLASS
WRITE(IOUT,610)I
610 FORMAT('0Enter the observed frequency for class ',I3)
READ*, OBSFRQ(I)
TOBSFR=TOBSFR+OBSFRQ(I)
WRITE(IOUT,615)I
615 FORMAT('0Enter the empirical relative frequency for class ',I3/
1' as a decimal fraction')
ULIM(I)=I
630 READ*, RELFRQ(I)
GO TO 700

700 DO 110 I=1,NCLASS
IF(ITEST .EQ. 0)TORLFR=TORLFR+OBSFRQ(I)/TOBSFR
IF(ITEST .EQ. 0)ORLFRQ(I)=TORLFR
IF(ITEST .EQ. 0)TTFRQ=TTFRQ+RELFRQ(I)

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IF(ITEST .EQ. 0)CTHFRQ(I)=TTFRQ
IF(ITEST .EQ. 0)ADIFF(I)=ABS(ORLFRQ(I)-CTHFRQ(I))
EXPFRQ(I)=TOBSFR*RELFRQ(I)
IF(EXPFRQ(I) .LT. 0.0001) CCHISQ(I)=999.99
IF(EXPFRQ(I) .LT. 0.0001) GO TO 110
CCHISQ(I)=((OBSFRQ(I)-EXPFRQ(I))**2)/EXPFRQ(I)
110 CONTINUE
IF(ITEST .EQ. 0)GO TO 900
WRITE(30,120)
WRITE(IOUT,120)
120 FORMAT('0',8X,'CLASS',3X,'OBSERVED',3X,'RELATIVE',
13X,'EXPECTED',3X,' CHI')
WRITE(30,130)
WRITE(IOUT,130)
130 FORMAT(1X,'CLASS',3X,'IDENT',3X,' FREQ. ',3X,' FREQ. ',
13X,' FREQ. ',3X,'SQUARE'/)
DO 140 I=1,NCLASS
TCHISQ=TCHISQ+CCHISQ(I)
TEXPFR=TEXPFR+EXPFRQ(I)
140 TRELFR=TRELFR+RELFRQ(I)
DO 150 I=1,NCLASS
WRITE(30,160)I,ULIM(I),OBSFRQ(I),RELFRQ(I),EXPFRQ(I),CCHISQ(I)
WRITE(IOUT,160)I,ULIM(I),OBSFRQ(I),RELFRQ(I),EXPFRQ(I),CCHISQ(I)
C CHANGED FROM 160 FORMAT(1X,I5,2X,F6.1,2X,F8.2,3X,F8.3,3X,F8.2,3X,F6.
C CHANGED TO
160 FORMAT(1X,I5,2X,F7.1,2X,F8.2,3X,F8.3,3X,F8.2,3X,F7.2)
150 CONTINUE
WRITE(30,170)TOBSFR,TRELFR,TEXPFR,TCHISQ
WRITE(IOUT,170)TOBSFR,TRELFR,TEXPFR,TCHISQ
170 FORMAT('0','**TOTALS** ',3X,F9.2,2X,F9.3,2X,F9.2,
13X,F6.2/)
IF(IDIST .EQ. 1 .OR. IDIST .EQ. 2)GO TO 210
IF(IDIST .EQ. 3)GO TO 220
NDF=NCLASS-1
WRITE(30,171)NDF
WRITE(IOUT,171)NDF
171 FORMAT('0Degrees of freedom equals number of classes '/'
1' minus one, or ',I3,'.')
MIN1=NDF
MIN2=NDF
GO TO 195
190 MIN1=NCLASS-NDF1
MIN2=NCLASS-NDF2
WRITE(30,172)NDF1,MIN1
WRITE(IOUT,172)NDF1,MIN1
172 FORMAT('0','If you used these observed data to estimate '
1'hypothesis parameters,'/' degrees of freedom equals '
2'number of classes minus ',I3,' or ',I3,'.')
WRITE(30,173)NDF2,MIN2
WRITE(IOUT,173)NDF2,MIN2
173 FORMAT('0','If you used an independent estimate of the '
1'hypothesis parameters, '/' degrees of freedom equals ',

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2 'number of classes minus ',I3,' or ',I3,'.')
195 IF(MIN1 .LE. 0 .OR. MIN2 .LE. 0)WRITE(IOUT,200)
   IF(MIN1 .LE. 0 .OR. MIN2 .LE. 0)WRITE(30,200)
200 FORMAT('0Degrees of freedom are dubious.')
   IF(MIN1 .GT. 0 .AND. MIN2 .GT. 0 .AND. IDIST .LE. 3
1.AND. MIN2 .LE. 20)WRITE(30,201)CHI(MIN1),MIN1,CHI(MIN2),MIN2
   IF(MIN1 .GT. 0 .AND. MIN2 .GT. 0 .AND. IDIST .LE. 3
1.AND. MIN2 .LE. 20)WRITE(IOUT,201)CHI(MIN1),MIN1,CHI(MIN2),MIN2
   IF(MIN1 .GT. 0 .AND. MIN2 .GT. 0 .AND. IDIST .GT. 3
1.AND. MIN1 .LE. 20)WRITE(30,202)CHI(MIN1),MIN1
   IF(MIN1 .GT. 0 .AND. MIN2 .GT. 0 .AND. IDIST .GT. 3
1.AND. MIN1 .LE. 20)WRITE(IOUT,202)CHI(MIN1),MIN1
201 FORMAT('0Critical chi-square values at the .05 level of',
1' significance are '/F9.3,' for ',I3,' degrees of freedom ',
2'and ',F8.3,' for ',I3,' degrees of freedom.')
202 FORMAT('0Critical chi-square value at the .05 level of',
1' significance is '/F9.3,' for ',I3,' degrees of freedom.')
203 DO 174 I=1,NCLASS
   EXPFRQ(I)=EXPFRQ(I)+.001
   IF(EXPFRQ(I) .LT. 5)GO TO 175
174 CONTINUE
   GO TO 178
175 WRITE(IOUT,176)
   WRITE(30,176)
176 FORMAT('0At least one expected frequency is less than 5.',
1' you might combine classes.')
178 WRITE(IOUT,180)
180 FORMAT('0If you want to solve another problem, type a 1.',
1' otherwise, type a 0.')
   READ*, J
   IF(J .EQ. 1) GO TO 1
   STOP
210 NDF1=2
   NDF2=1
   GO TO 190
220 NDF1=3
   NDF2=1
   GO TO 190
900 WRITE(IOUT,910)
   WRITE(30,910)
910 FORMAT('0',26X,'OBSERVED',3X,'THEORETICAL')
   WRITE(30,915)
   WRITE(IOUT,915)
915 FORMAT(8X,'CLASS',2X,'OBSERVED',3X,'CUMULATIVE',2X,
1'CUMULATIVE',4X,'ABSOLUTE')
   WRITE(30,920)
   WRITE(IOUT,920)
920 FORMAT(1X,'CLASS',2X,'IDENT',2X,'FREQUENCY',2X,
1'PROPORTION',2X,'PROPORTION',3X,'DIFFERENCE')
   DO 940 I=1,NCLASS
   WRITE(30,930)I,ULIM(I),OBSFRQ(I),ORLFRQ(I),CTHFRQ(I),ADIFF(I)
   WRITE(IOUT,930)I,ULIM(I),OBSFRQ(I),ORLFRQ(I),CTHFRQ(I),ADIFF(I)

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930  FORMAT(1X,I5,1X,F6.1,4X,F5.0,5X,F6.4,6X,F6.4,8X,F6.4)
      IF(ADIFF(I) .GT. DIFF) DIFF=ADIFF(I)
940  CONTINUE
      WRITE(30,945)TOBSFR
      WRITE(IOUT,945)TOBSFR
945  FORMAT('0',' ***TOTAL***',3X,F6.0)
      WRITE(30,950)DIFF
      WRITE(IOUT,950)DIFF
950  FORMAT('0the maximum sample difference is ',F8.4)
      IF(TOBSFR .LE. 35)CXKS=XKS(TOBSFR)
      IF(TOBSFR .GT. 35)CXKS=1.36/SQRT(TOBSFR)
      WRITE(30,960)CXKS
      WRITE(IOUT,960)CXKS
960  FORMAT('0THE CRITICAL VALUE OF D IS ',F8.4,'AT .05 LEVEL')
      GO TO 178
      END
      FUNCTION FCTRL(NUM)
      FCTRL = 1
      IF(NUM .EQ. 0 .OR. NUM .EQ. 1)GO TO 9001
      DO 9000 L=1,NUM
9000  FCTRL=FCTRL*L
9001  RETURN
      END
```

APPENDIX E
SIMULATION PROGRAM AND SAMPLE OUTPUT

C*****
C***** PROGRAMMER: PRABIR K. BAGCHI
C*****
C***** THIS PROGRAM, BASED ON SLAM II SIMULATION PACKAGE, SIMULATES THE
C***** OPERATION OF A CONSOLIDATION CENTER. EACH CONSOLIDATION CENTER
C***** IS ASSIGNED A TERRITORY WHICH IT SERVES. SHIPMENTS WITHIN THIS
C***** TERRITORY ARE SENT TO THE CONSOLIDATION CENTER WHERE
C***** THEY ARE HELD FOR A SPECIFIC HOLDING TIME. ON THE EXPIRY OF
C***** THE HOLDING TIME THE ACCUMULATED LOAD IS DISPATCHED TO THE
C***** DESTINATION. SUCH CONSOLIDATED SHIPMENTS ARE DISPATCHED AT
C***** PREDETERMINED INTERVALS. THIS IS KNOWN AS SCHEDULED SHIPMENT
C***** STRATEGY. VENDORS LOCATED OUTSIDE THE TERRITORY OF A CONSOLIDATION
C***** CENTER DISPATCH SHIPMENTS DIRECT TO THE DESTINATION. IF AT
C***** EXPIRY OF THE SCHEDULED HOLDING TIME LOAD ACCUMULATED IS NOT
C***** ADEQUATE TO JUSTIFY FULL TRUCK SHIPMENT, THEN THE SHIPMENT IS
C***** DISPATCHED AS A REGULAR LESS THAN TRUCK LOAD SHIPMENT. THIS
C***** PROGRAM SIMULATES THE PROCUREMENT SYSTEM FOR 250 DAYS OPERATIONS
C***** FOR DIFFERENT SYSTEM CONFIGURATIONS.
C*****

10	CUMULATIVE PROBABILITY DISTRIBUTION OF ORIGIN ZIP CODES
11	VENDORS' HISTORICAL LOAD DATA
12	LOCAL PICK-UP RATES FOR CONSOLIDATION CENTER 1
13	TRUCK-LOAD RATES FROM CONSOLIDATION CENTERS TO DESTINATIONS
14	LTL RATES FROM CONSOL CENTER 1 TO TO DESTINATION 1
15	LTL RATES ORIGIN TO DESTINATION (NUMEARX)
16	MILEAGES: ORIGIN TO CONSOL CENTER 1
17	MILEAGES: ORIGIN TO DESTINATION
18	MILEAGE-BASED LINE-HAUL RATES
20	CUMULATIVE PROBABILITY DISTRIBUTION VENDORS' ORIGIN FOR DEST. 2
21	VENDORS' LOAD DATA FOR DEST. 2
25	LTL RATES FROM ORIGIN TO DEST. 2 (NUMEARX)
32	LOCAL PICK-UP RATES FOR CONSOL CENTER 2
36	MILEAGE: ORIGIN TO CONSOL CENTER 2

LIST OF THE VARIABLES USED IN THE PROGRAM ARE GIVEN BELOW:

LOAD	:	SHIPMENT WEIGHT
TIN	:	TIME SHIPMENT IN

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C**** TOUT : TIME SHIPMENT REACHES DESTINATION
C**** NS : NUMBER OF CONSOLIDATED SHIPMENTS(ONE CENTER)
C**** NS1 : NUMBER OF CONSOLIDATED SHIPMENTS CENTER 1
C**** NS2 : NUMBER OF CONSOLIDATED SHIPMENTS CENTER 2
C**** LMAX : AVERAGE FULL TRUCKLOAD SHIPMENT WEIGHT
C**** HOLD : HOLDING TIME, DAYS AT THE CONSOLIDATION CENTER
C**** TLCSOT : TOTAL CONSOLIDATION SYSTEMS COST
C**** IFLAG : POINTER TO INDICATE START OF SIMULATION
C**** TTIME : TRANSIT TIME, CONSOLIDATED SHIPMENTS(ONE CENTER)
C**** TTIME1 : TRANSIT TIME, CONSOLIDATED SHIPMENTS CENTER 1
C**** TTIME2 : TRANSIT TIME, CONSOLIDATED SHIPMENTS CENTER 2
C**** ORDR : NUMBER OF ORDERS GENERATED EACH DAY
C**** LODYTD : LOAD GENERATED DURING THE YEAR TILL DATE
C**** NTL : NUMBER OF TRUCKLOAD SHIPMENTS MADE(ONE CENTER)
C**** NTL1 : NUMBER OF TRUCKLOAD SHIPMENTS MADE CENTER 1
C**** NTL2 : NUMBER OF TRUCKLOAD SHIPMENTS MADE CENTER 2
C**** NSL : NUMBER OF LOADS SUPPLIED BY VENDORS
C**** CSTLTL : COST OF DIRECT SHIPMENT FROM VENDORS
C**** LCCST : LOCAL CARTAGE AND CONSOLIDATION COST
C**** LHCST : FULL TRUCKLOAD RATE FROM CENTER 1
C**** LHCST2 : FULL TRUCKLOAD RATE FROM CENTER 2
C**** TPCST : TEMPORARY LINE-HAUL COST FOR COMPARISON
C**** LNCST : LINE-HAUL COST OF CONSOLIDATED SHIPMENT ONE CENTER
C**** LNCST1 : LINE-HAUL COST OF CONSOLIDATED SHIPMENT CENTER 1
C**** LNCST2 : LINE-HAUL COST OF CONSOLIDATED SHIPMENT CENTER 2
C**** DIRCST : COST OF DIRECT DISPATCH FROM VENDORS WHEN VENDORS ARE LOCATED OUTSIDE CONSOL CENTER TERRITORY
C**** NDL : NUMBER OF DIRECT DISPATCHES MADE FROM VENDORS
C**** NL : LOCATED OUTSIDE CONSOL CENTER TERRITORY
C**** NL : TOTAL NUMBER OF SHIPMENTS GENERATED IN A SPECIFIC PERIOD
C**** LRAT(300,10) : LOCAL PICK-UP RATE MATRIX FROM ORIGIN TO CONSOLIDATION CENTER
C**** LRATE : SPECIFIC LOCAL PICK-UP RATE
C**** LTLRAT(300,10) : LTL RATES OBTAINED FROM NUMERAX FROM ORIGIN TO DESTINATION
C**** LTRATE : LTL RATE FOR SPECIFIC COMBINATION
C**** DIST(300,3) : DISTANCE MATRIX FROM ORIGIN TO CONSOL CENTER
C**** XDIST : SPECIFIC ORIGIN-CONSOL CENTER DISTANCE
C**** XTIME : LTL TRANSIT TIME
C**** DIST2(300,5) : DISTANCE MATRIX FROM ORIGIN TO DESTINATIONS
C**** YDIST : SPECIFIC ORIGIN TO DEST. DISTANCE
C**** LHDIST : SPECIFIC CONSOL CENTER TO DEST. DISTANCE
C**** DIST3(300,3) : DISTANCE MATRIX ORIGIN TO CONSOL CENTER 2
C**** CZIP : 3-DIGIT ZIP CODE CONSOLIDATION CENTER 1
C**** CZIP2 : 3-DIGIT ZIP CODE CONSOL CENTER 2
C**** DZIP : 3-DIGIT ZIP CODE DESTINATION
C**** MAXO : CONSOLIDATION CENTER BOUNDARY IN 100 MILES
C**** LFACTOR : LOAD FACTOR
C**** OFACTR : ORDER NUMBER FACTOR
C**** NCNTR : NUMBER OF CONSOLIDATION CENTERS

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C**** VARIABLE IN COMMON/SCOM1 ARE ALL SLAM SPECIFIC VARIABLES
C**** AS DESCRIBED IN PRITSKER'S TEXT ON SIMULATION AND SLAM.

C****
C****
G****

1	ISN	PROGRAM MAIN
2	ISN	DIMENSION NSET(150000)
3	ISN	COMMON/SCOM1/ATTRIB(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
4	ISN	1,NCRDR,NPRNT,NRUN,NSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
5	ISN	COMMON/UCOM1/LOAD,TIN,TOUT,NS,LMAX,HOLD,TLRAT,TLRAT,TIME,ORDR
6	ISN	1,LODYTD,NS1,NS2,NL,TTIME1,TTIME2
7	ISN	COMMON/VCOM1/NSL,CSTLTL,LOCST,LHCAST,TPCST,LNCST,DIRCST,NDL,NL
8	ISN	1,LHCAST,LHDSST2,LNCST1,LNCST2
9	ISN	COMMON/WCOM1/LRAT(300,10),LRATE,TLRAT(300,10),LTRATE,DIST(300,3)
10	ISN	1,XDIST,XTIME,DIST2(300,5),YDIST,LHDSST,DIST3(300,3)
11	ISN	COMMON/WCOM2/CZIP,CZIP2,DZIP,MAXD,LFACTR,OFACR,MILPTR,NCNTR
12	ISN	COMMON/WCOM3/SUMPRD,SUMTIM,SUMTM1,SUMTM2
13	ISN	COMMON/WCOM4/SUMTMP,NSLTMP,TMPTIM,NSTMP,TMPTM1,TMPTM2
14	ISN	COMMON/WCOM5/TLRATE(50,10)
15	ISN	COMMON QSET(150000)
16	ISN	REAL LRAT,LRATE,TLRAT,LRATE,DIST,XDIST,DIST2,YDIST,LHDSST2
17	ISN	1,TLRATE
18	ISN	REAL LOCST,TLRAT,LHCAST,TPCST,LNCST,CSTLTL,DIRCST,LHDSST2
19	ISN	REAL CZIP,DZIP,MAXD,LFACTR,OFACR,LODYTD,CZIP2,LNCST1,LNCST2
20	ISN	EQUIVALENCE (NSET(1),QSET(1))
21	ISN	EQUIVALENCE (TLRAT,XX(1))
22	ISN	EQUIVALENCE (TLRAT,XX(2))
23	ISN	EQUIVALENCE (TLRAT,XX(3))
24	ISN	NSSET=150000
25	ISN	NCRDR=5
26	ISN	NPRNT=6
27	ISN	NTAPE=7
28	ISN	LODYTD=0.
29	ISN	LRATE=0.
30	ISN	LTRATE=0.
31	ISN	SUMPRD=0.
32	ISN	SUMTIM=0.
33	ISN	SUMTM1=0.
34	ISN	SUMTM2=0.
35	ISN	TMPTIM=0.
36	ISN	TMPTM1=0.
37	ISN	TMPTM2=0.
38	ISN	SUMTMP=0.
39	ISN	NSLTMP=0.
40	ISN	NSTMP=0.
41	ISN	NTL=0
42	ISN	SPECIFY HOLDING TIME AT THE CONSOLIDATION CENTER
43	ISN	HOLD=7.0
44	ISN	SPECIFY LOCATION OF THE CONSOLIDATION CENTER BY ASSIGNING A
45	ISN	C**** VALUE TO CZIP
46	ISN	C**** CZIP=606.


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39  ISN      CZIP2=452.
40  ISN      SPECIFY DESTINATION BY ASSIGNING A VALUE TO DZIP
41  ISN      DZIP=230.
42  ISN      ASSIGN THE MAXIMUM DISTANCE OF THE ORIGIN TO BE ASSIGNED
43  ISN      TO A CONSOLIDATION CENTER
44  ISN      MAXD=100.
45  ISN      ASSIGN A VALUE TO LOAD FACTOR.  LFACTR ENABLES US TO CHANGE
46  ISN      THE MEAN SHIPMENT WEIGHT KEEPING THE LOAD DISTRIBUTION
47  ISN      UNCHANGED.
48  ISN      LFACTR=1.00
49  ISN      ASSIGN A VALUE TO ORDER NUMBER FACTOR.  OFACTR ENABLES US TO
50  ISN      CHANGE MEAN NUMBER OF ORDERS/SHIPMENTS RECEIVED AT A
51  ISN      CONSOLIDATION CENTER.
52  ISN      OFACTR=1.00
53  ISN      IF THE STUDY IS BASED ON A MILEAGE BASED RATE ASSIGN A VALUE
54  ISN      1 TO THE VARIABLE MILPTR.
55  ISN      MILPTR=0
56  ISN      IF NUMBER OF CONSOLIDATION CENTERS ARE MORE THAN ONE ASSIGN
57  ISN      APPROPRIATE VALUE TO NCNTR.
58  ISN      NCNTR=1
59  ISN      CALL SLAM
60  ISN      STOP
61  ISN      END
62  ISN      SOURCE STATEMENTS = 48, PROGRAM SIZE = 2834 BYTES, PROGRAM NAME = MAIN
63  ISN      NO DIAGNOSTICS GENERATED.
64  ISN      *****
65  ISN      C
66  ISN      C
67  ISN      SUBROUTINE ARVL
68  ISN      COMMON/SCOM1/ATRIB(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
69  ISN      1,NCRDR,NPRNT,NMRUN,NNSSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
70  ISN      COMMON/UCOM1/LOAD,TIN,TOUT,NS,LMAX,HOLD,TLCOST,IFLAG,TTIME,ORDR
71  ISN      1,LODYTD,NS1,NS2,NIL,TTIME1,TTIME2
72  ISN      COMMON/VCOM1/NSL,CSTLTL,LOCOST,LHCOST,TPCOST,LNCOST,DIRCST,NDL,NL
73  ISN      1,LHCST2,LHDS2,LNCST1,LNCST2
74  ISN      COMMON/WCOM1/LRAT(300,10),LRATE,LILRAT(300,10),LIRATE,DIST(300,3)
75  ISN      1,XDIST,XTIME,DIST2(300,5),YDIST,LHDS1,LHDS2,DIST3(300,3)
76  ISN      COMMON/WCOM2/CZIP,CZIP2,DZIP,MAXD,LFACTR,OFACTR,MILPTR,NCNTR
77  ISN      COMMON/WCOM3/SUMPRD,SUMTIM
78  ISN      COMMON/WCOM5/TLRATE(50,10)
79  ISN      COMMON QSET(30000)
80  ISN      REAL ORGZP(1000),OZIP,LOAD,RATE,LOCRT(400,10),TLRATE,XDIST
81  ISN      1,DIST2,YDIST,LHDS1,LODYTD,LOCRT2(400,10),DIST3,XDIST3
82  ISN      REAL HI(1000),LO(1000),FX(1000),XVAL(1000),LRAT,LRATE,LILRAT,DIST
83  ISN      REAL LOCOST,TLCOST,LHCOST,TPCOST,LNCOST,LHCST2,LTSCALE,CSTLTL,DIRCST
84  ISN      1,LNCST1,LNCST2
85  ISN      REAL CZIP,DZIP,MAXD,LFACTR,OFACTR,CZIP2,TMPDST,TLOAD1,TLOAD2,LHDS2
86  ISN      EQUIVALENCE(TLOAD,XX(1))
87  ISN      EQUIVALENCE(TLOAD1,XX(2))
88  ISN      EQUIVALENCE(TLOAD2,XX(3))
89  ISN      NTMP=NSL
90  ISN
91  ISN
92  ISN
93  ISN
94  ISN
95  ISN
96  ISN
97  ISN
98  ISN
99  ISN
100 ISN
101 ISN
102 ISN
103 ISN
104 ISN
105 ISN
106 ISN
107 ISN
108 ISN
109 ISN
110 ISN
111 ISN
112 ISN
113 ISN
114 ISN
115 ISN
116 ISN
117 ISN

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```

18      IF(TNOW.GT.O.)THEN
19      IF(TNOW.EQ.1.) THEN
C**** LOAD SUPPLIES BY ZIPCODE FOR EACH DESTINATION
C**** ZIPCODE 331=MIAMI, FLORIDA
C**** ZIPCODE 230=ASHLAND, VIRGINIA
20      IF(DZIP.EQ. 331.) NUNIT=10
21      IF(DZIP.EQ. 230.) NUNIT=10
22      ICOUNT=1
23      REWIND (UNIT=NUNIT)
24      READ(NUNIT,*) IK,XVAL(ICOUNT),FX(ICOUNT)
25      WRITE(NPRNT,*) IK,XVAL(ICOUNT),FX(ICOUNT),'XXX'
26      IF(IK.NE.999) THEN
C
27      ICOUNT=ICOUNT+1
28      READ(NUNIT,*) IK,XVAL(ICOUNT),FX(ICOUNT)
29      WRITE(NPRNT,*) IK,XVAL(ICOUNT),FX(ICOUNT)
30      GO TO 15
31      ENDIF
32      KK=1
33      XVAL(ICOUNT)=0.
34      FX(ICOUNT)=0.
35      ICOUNT=ICOUNT-1
C**** READING MAXIMUM AND MINIMUM LOADS ORIGINATING FROM EACH
C**** ORIGIN ZIPCODE
36      IF(DZIP.EQ. 331.) NUNIT=11
37      IF(DZIP.EQ. 230.) NUNIT=11
38      REWIND (UNIT=NUNIT)
39      READ(NUNIT,*) HI(KK),LO(KK),ORGZP(KK)
40      WRITE(NPRNT,*) HI(KK),LO(KK),ORGZP(KK)
41      IF(HI(KK).NE.999.) THEN
C
42      KK=KK+1
43      READ(11,*) HI(KK),LO(KK),ORGZP(KK)
44      WRITE(NPRNT,*) HI(KK),LO(KK),ORGZP(KK)
45      GO TO 19
46      ENDIF
C**** READING LOCAL CARTAGE RATES FOR THE CONSOLIDATION CENTER1(CHICAGO)
47      REWIND (UNIT=12)
48      DO 50 I1=1,300
49      READ(12,*)(LOCRT(11,JJ),JJ=1,8)
50      WRITE(NPRNT,*)(LOCRT(11,JJ),JJ=1,8)
C
51      CONTINUE
C**** READING LOCAL CARTAGE RATES FOR THE CONSOLIDATION CENTER 2
C**** AT CINCINNATI
52      REWIND (UNIT=32)
53      DO 55 I11=1,300
54      READ(32,*)(LOCRT2(111,JJJ),JJJ=1,8)
55      WRITE(NPRNT,*)(LOCRT2(111,JJJ),JJJ=1,8)
56      CONTINUE
C**** READING LINE-HAUL(TL) RATE MATRIX
C****
57      REWIND (UNIT=13)
58      DO 60 LL=1,24

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ISN 57      READ(13,*)(TLRATE(LL,MM),MM=1,8)
ISN          WRITE(NPRNT,*)(TLRATE(LL,MM),MM=1,8)
C 60      CONTINUE
C****    READING LTL RATE MATRIX FOR CONSOL CENTER TO DESTINATION
C****    DISPATCHES FOR USE WHEN ACCUMULATED LOAD DO NOT JUSTIFY FULL-TRUCK
C****    SHIPMENT
ISN 59      REWIND (UNIT=14)
ISN 60      DO 150 IJ=1,24
ISN 61      READ(14,*)(LRAT(IJ,IK),IK=1,9)
ISN          WRITE(NPRNT,*)(LRAT(IJ,IK),IK=1,9)
ISN 62      CONTINUE
C 150
C****    IF LTL RATES ARE BASED ON MILE-RATES RATHER THAN ACTUAL
C****    GO TO 251
C****    IF(MILPTR.EQ. 1) GO TO 251
ISN 63      READING LTL RATE MATRIX FOR ORIGIN TO DESTINATION DIRECT
C****    DISPATCHES UNDER NO-CONSOLIDATION SHIPMENT SCHEME
ISN 64      IF(DZIP.EQ. 331.) LUNIT=15
ISN 66      IF(DZIP.EQ. 230.) LUNIT=25
ISN 68      REWIND (UNIT=LUNIT)
ISN 69      DO 250 JJ=1,300
ISN 70      READ(LUNIT,*)(LTLRAT(JJ,JK),JK=1,9)
ISN          WRITE(NPRNT,*)(LTLRAT(JJ,JK),JK=1,9)
ISN 71      CONTINUE
ISN 72      IF(MILPTR.NE. 1) GO TO 256
ISN 73      CONTINUE
C 250
C****    READING MILE-BASED LINE-HAUL RATES AS USED BY THE ORGANIZATION
C****    WHOSE DATA HAS BEEN USED HERE. THIS IS NECESSARY FOR
C****    COMPARISON WITH ACTUAL.
ISN 74      REWIND (UNIT=18)
ISN 75      DO 255 JL=1,62
ISN 76      READ(18,*)(LTLRAT(JL,JM),JM=1,7)
ISN          WRITE(NPRNT,*)(LTLRAT(JL,JM),JM=1,7)
ISN 77      CONTINUE
C 255
C****    CONTINUE
ISN 78      CONTINUE
C****    READING THE DISTANCE MATRIX BETWEEN THE ORIGINS AND THE
C****    CONSOLIDATION CENTER NO. 1 AT CHICAGO
ISN 79      REWIND (UNIT=16)
ISN 80      DO 350 KK=1,300
ISN 81      READ(16,*)(DIST(KK,KL),KL=1,3)
ISN 82      CONTINUE
C 350
C****    READING THE DISTANCE MATRIX BETWEEN THE ORIGINS AND THE
C****    CONSOLIDATION CENTER NO. 2 AT CINCINNATI
ISN 83      REWIND (UNIT=36)
ISN 84      DO 355 KKK=1,300
ISN 85      READ(36,*)(DIST3(KKK,KKL),KKL=1,3)
ISN 86      CONTINUE
C 355
C****    READING THE DISTANCE MATRIX BETWEEN THE ORIGINS AND THE
C****    DESTINATIONS

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87 ISN      REVIND (UNIT=17)
88 ISN      DO 450 IL=1,300
89 ISN      READ(17,*)(DIST2(IL,LI),LI=1,5)
          WRITE(NPRNT,*)(DIST2(IL,LI),LI=1,5)
90 ISN      C
91 ISN      CONTINUE
          ENDIF

C****
C**** NUMBR IS THE NUMBER OF INBOUND SHIPMENTS ORIGINATING IN THE
C**** REGION UNDER CONSIDERATION EVERYDAY, ROUNDED TO THE
C**** NEAREST INTEGER.
29 C**** NUMBR=INT(NPSSN(3.,3)*OFACTR+0.50)
92 ISN      IF(NUMBR.EQ.0) GO TO 101
93 ISN      FNUMBR=REAL(NUMBR)
94 ISN      ATTRIB(2)=NUMBR
C
C      ATTRIB(3)=NUMBR*ATTRIB(1)
C
95 ISN      WRITE(NPRNT,99)NUMBR
99 FORMAT(1X,'NUMBER OF SHIPMENTS RECEIVED:',15)
C**** COLLECT STATISTICS ON NUMBER OF INBOUND SHIPMENTS RECEIVED AT THE
C**** CONSOLIDATION CENTER
CALL COLCT(FNUMBR,2)
DO 100 I=1,NUMBR
C**** NL IS THE TOTAL NUMBER OF LOADS ORIGINATING DURING THE PERIOD
C**** UNDER CONSIDERATION.
NL=NL+1
OZIP=DPROB(FX,XVAL,ICOUNT,2)
98 ISN      WRITE(NPRNT,199) OZIP
99 ISN      FORMAT(1X,'ORIGIN ZIP CODE:',1,F5.0)
100 ISN      ICT=1
101 ISN      IF(ORGZP(ICT).EQ.OZIP) GO TO 40
102 ISN      ICT=ICT+1
103 ISN      GO TO 399
104 ISN      CONTINUE
105 ISN      WRITE(NPRNT,*) ICT,LO(ICT),HI(ICT)
          IF(LO(ICT).NE.HI(ICT))THEN
              LOAD=UNFRM(LFACTR*LO(ICT),LFACTR*HI(ICT),1)
          ELSE
              LOAD=LFACTR*LO(ICT)
          ENDIF
          LODYTD=LODYTD+LOAD
          WRITE(NPRNT,999)LOAD,I,LODYTD
          FORMAT(1X,'LOAD RECD:',1,F10.2,3X,'LOAD NO:',15,'LYTD'
106 ISN      1,F14.2)
107 ISN      C
108 ISN      999
109 ISN      C**** IF THERE ARE MORE THAN ONE CONSOLIDATION CENTERS IN THE
110 ISN      C**** SYSTEM THEN GO TO 159
111 ISN      IF(NCNR.GT.1) GO TO 159
112 ISN      C**** FINDING THE DISTANCE OF THE ORIGIN FROM THE CONSOLIDATION
113 ISN      C**** CENTER FROM THE DISTANCE MATRIX
114 ISN      C**** XDIST=ORIGIN TO CONSOLIDATION CENTER DISTANCE
115 ISN      DO 69 M=1,300
116 ISN      IF(DIST(M,1).EQ.OZIP .AND. DIST(M,2).EQ.CZIP) THEN
          XDIST=DIST(M,3)

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```

117 ISN
118 ISN
119 ISN
120 ISN
121 ISN
122 ISN
123 ISN
124 ISN
125 ISN
126 ISN
127 ISN
128 ISN
129 ISN
130 ISN
131 ISN
132 ISN
133 ISN
134 ISN
135 ISN

136 ISN
137 ISN
138 ISN
139 ISN
140 ISN
141 ISN
142 ISN
143 ISN
144 ISN
145 ISN

147 ISN
148 ISN
149 ISN
150 ISN
151 ISN
152 ISN
153 ISN
154 ISN
155 ISN
156 ISN
157 ISN
158 ISN
159 ISN
160 ISN
161 ISN
162 ISN
163 ISN

117 ENDIF
118 CONTINUE
119 WRITE(NPRNT,*) 'XDIST',XDIST
120 IF(NCNR .EQ. 1) GO TO 161
121 DO 160 MM=1,300
122 IF(DIST(MM,1) .EQ. OZIP .AND. DIST(MM,2) .EQ. CZIP) THEN
123 TMPDST=DIST(MM,3)
124 ENDIF
125 IF(DIST3(MM,1) .EQ. OZIP .AND. DIST3(MM,2) .EQ. CZIP2) THEN
126 XDIST3=DIST3(MM,3)
127 ENDIF
128 CONTINUE
129 IF(XDIST3 .LT. TMPDST) THEN
130 XDIST=XDIST3
131 IPTR=2
132 ELSE
133 XDIST=TMPDST
134 IPTR=1
135 ENDIF
136 WRITE(NPRNT,*) 'ORGN TO CONSOL:',XDIST, 'TMPDST',TMPDST, 'MAXD',MAXD
137 CONTINUE
138 C****
139 C**** FINDING THE DISTANCE OF THE ORIGIN FROM THE DESTINATION
140 C**** FROM THE ORIGIN-DESTINATION DISTANCE MATRIX
141 C**** YDIST=ORIGIN TO DESTINATION DISTANCE
142 NCTR=OZIP-400
143 IF(DZIP .EQ. 331.) YDIST=DIST2(NCTR,1)
144 IF(DZIP .EQ. 230.) YDIST=DIST2(NCTR,2)
145 IF(DZIP .EQ. 467.) YDIST=DIST2(NCTR,3)
146 IF(DZIP .EQ. 750.) YDIST=DIST2(NCTR,4)
147 IF(DZIP .EQ. 890.) YDIST=DIST2(NCTR,5)
148 WRITE(NPRNT,*) 'ORGN TO DEST',YDIST
149 TABLE LOOKUP
150 C**** CHECKING FROM LOCAL CARTAGE RATES AND LOAD GENERATED AT A
151 C**** PARTICULAR ORIGIN ZIP AS TO WHICH RATE IS APPLICABLE FOR
152 C**** TRANSPORTING TO THE CONSOLIDATION CENTER.
153 C**** IF IPTR=1 THEN WE SHALL FIND THE APPROPRIATE RATE FOR THE
154 C**** CONSOLIDATION CENTER GIVEN BY CZIP, IF IPTR=2 THEN WE
155 C**** SHALL FIND THE SAME FOR THE CONSOLIDATION CENTER GIVEN BY
156 C**** CZIP2.
157 IF(IPTR .EQ. 1) GO TO 270
158 IF(IPTR .EQ. 2) GO TO 275
159 DO 70 L=1,300
160 IF(LOCRA(L,1).EQ. OZIP .AND. LOCRA(L,2).EQ. CZIP) THEN
161 IF(LOAD.LT.500.)RATE=LOCRA(L,3)
162 IF(LOAD.GE.500. .AND. LOAD.LT.1000.)RATE=LOCRA(L,4)
163 IF(LOAD.GE.1000. .AND. LOAD.LT.2000.)RATE=LOCRA(L,5)
164 IF(LOAD.GE.2000. .AND. LOAD.LT.5000.)RATE=LOCRA(L,6)
165 IF(LOAD.GE.5000. .AND. LOAD.LT.10000.)RATE=LOCRA(L,7)
166 IF(LOAD.GE.10000.)RATE=LOCRA(L,8)
167 ENDIF

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164 ISN 70 CONTINUE
165 ISN 275 DO 280 LLL=1,300
166 ISN IF(LOCRT2(LLL,1).EQ. OZIP .AND. LOCRT2(LLL,2).EQ. CZIP2) THEN
167 ISN IF(LOAD.LT.500.)RATE=LOCRT2(LLL,3)
168 ISN IF(LOAD.GE.500. .AND. LOAD.LT.1000.)RATE=LOCRT2(LLL,4)
169 ISN IF(LOAD.GE.1000. .AND. LOAD.LT.2000.)RATE=LOCRT2(LLL,5)
170 ISN IF(LOAD.GE.2000. .AND. LOAD.LT.5000.)RATE=LOCRT2(LLL,6)
171 ISN IF(LOAD.GE.5000. .AND. LOAD.LT.10000.)RATE=LOCRT2(LLL,7)
172 ISN IF(LOAD.GE.10000.)RATE=LOCRT2(LLL,8)
173 ISN ENDIF
174 ISN 280 CONTINUE
175 ISN C**** TABLE LOOKUP FROM NUMERAX RATE DATA TO FIND ORIGIN TO
176 ISN C**** FINAL DESTINATION LTL RATE
177 ISN IF(MILPTR .EQ. 1) GO TO 171
178 ISN DO 170 LLL=1,300
179 ISN IF(LTLRAT(LLL,1).EQ.OZIP .AND. LTLRAT(LLL,2).EQ.DZIP)THEN
180 ISN IF(LOAD.LT.500.)LTRATE=LTLRAT(LLL,4)
181 ISN IF(LOAD.GE.500. .AND. LOAD.LT.1000.)LTRATE=LTLRAT(LLL,5)
182 ISN IF(LOAD.GE.1000. .AND. LOAD.LT.2000.)LTRATE=LTLRAT(LLL,6)
183 ISN IF(LOAD.GE.2000. .AND. LOAD.LT.5000.)LTRATE=LTLRAT(LLL,7)
184 ISN IF(LOAD.GE.5000. .AND. LOAD.LT.10000.)LTRATE=LTLRAT(LLL,8)
185 ISN IF(LOAD.GE.10000.)LTRATE=LTLRAT(LLL,9)
186 ISN IF((LOAD*LTRATE)/100.).LT.LTLRAT(LLL,3)) LTRATE=LTLRAT(LLL,3)
187 ISN C
188 ISN ENDIF
189 ISN 170 CONTINUE
190 ISN IF(MILPTR .NE. 1) GO TO 172
191 ISN CONTINUE
192 ISN LCTR=INT(YDIST/50)-3
193 ISN IF(MOD(INT(YDIST),50).EQ. 0) LCTR=LCTR-1
194 ISN IF(LOAD.LT.500.)LTRATE=LTLRAT(LCTR,2)
195 ISN IF(LOAD.GE.500. .AND. LOAD.LT.1000.)LTRATE=LTLRAT(LCTR,3)
196 ISN IF(LOAD.GE.1000. .AND. LOAD.LT.2000.)LTRATE=LTLRAT(LCTR,4)
197 ISN IF(LOAD.GE.2000. .AND. LOAD.LT.5000.)LTRATE=LTLRAT(LCTR,5)
198 ISN IF(LOAD.GE.5000. .AND. LOAD.LT.10000.)LTRATE=LTLRAT(LCTR,6)
199 ISN IF(LOAD.GE.10000.)LTRATE=LTLRAT(LCTR,7)
200 ISN IF((LOAD*LTRATE)/100.).LT. LTLRAT(LCTR,1))LTRATE=LTLRAT(LCTR,1)
201 ISN C
202 ISN 172 CONTINUE
203 ISN C WRITE(NPRNT,*)'LTRATE',LTRATE
204 ISN C FINDING DIRECT COST OF SHIPMENT FROM ORIGIN TO DESTINATION
205 ISN C**** WHEN THE ORIGIN OUTSIDE THE CONSOLIDATION CENTER
206 ISN C**** BOUNDARY, AS DEFINED BY MAXD.
207 ISN IF(XDIST .LE. MAXD) GO TO 599
208 ISN DIRCST=DIRCST+LOAD*LTRATE/10000.
209 ISN NDL=NDL+1
210 ISN GO TO 111
211 ISN 599 CONTINUE
212 ISN C**** CALCULATING THE COST OF TRANSPORTING TO THE CONSOLIDATION
213 ISN C**** CENTER INCLUDING THE COST FOR CONSOLIDATION.
214 ISN LOCCST=LOCCST+LOAD*RATE/10000.+LOAD*1./100.
215 ISN C WRITE(NPRNT,*) LOCCST
216 ISN C**** SAVE TIME SPENT IN THE CONSOLIDATION CENTER BY EACH
217 ISN
218 ISN
219 ISN
220 ISN
221 ISN
222 ISN
223 ISN

```

```

**** SHIPMENT AND COLLECT STATISTICS.
  224  ATRIB(1)=HOLD-MOD(INT(TNOW),INT(HOLD))
  225  CALL COLCT(ATRIB(1),4)
**** FINDING THE NUMBER OF SMALL SHIPMENTS THAT ARE RECEIVED
**** AT THE CONSOLIDATION CENTER FROM SOURCES LOCATED IN ITS
**** VICINITY.  NSL=NUMBER OF SMALL LOADS
  226  NSL=NSL+1
  227  IF((NSL-NTMP).GT. 0) THEN
  228    ATRIB(2)=NSL-NTMP
  229    ATRIB(3)=ATRIB(1)*ATRIB(2)
  230    SUMPRD=SUMPRD+ATRIB(3)
  231    CALL FILEM(1,ATRIB)
  232    NTMP=NSL
  233  ENDIF
**** DETERMINE TOTAL CONSOLIDATED LOAD FOR ONE CONSOLIDATION
**** CENTER CASE
  234  TLOAD=TLOAD+LOAD
**** DETERMINE CONSOLIDATED LOAD FOR TWO CONSOLIDATION
**** CENTER CASE
  235  IF(IPIR.EQ. 1) TLOAD1=TLOAD1+LOAD
  237  IF(IPIR.EQ. 2) TLOAD2=TLOAD2+LOAD
  C    WRITE(NPRNT,*)'WTG TIME',ATRIB(1),'NUMBER',ATRIB(2)
  C    WRITE(NPRNT,*)'PRODUCT',ATRIB(3)
  C    WRITE(NPRNT,*)'TLOAD1',TLOAD1,'TLOAD2',TLOAD2
  C    WRITE(NPRNT,*)'MOVING TOTAL LOAD:',TLOAD,'SUMPRD',SUMPRD
  239  111 CONTINUE
**** FINDING THE COST OF SHIPPING DIRECT FROM ORIGIN TO
**** DESTINATION AS SMALL SHIPMENTS
  240  C**** CSTLTL=COST OF SHIPPING AS LTL SHIPMENT DIRECT FROM ORIGIN
  C**** TO DESTINATION UNDER NO-CONSOLIDATION SHIPMENT SCHEME
  C**** CSTLTL=CSTLTL+(LOAD*LTRATE)/10000.
  C    WRITE(NPRNT,*)'LTL COST:',CSTLTL
  C**** DETERMINE TRANSIT TIME FOR DIRECT LTL DISPATCHES UNDER
  C**** NO CONSOLIDATION
  C**** LTL DISPATCH TIME=PICK-UP TIME+TRANSIT TIME
  C**** PICK-UP TIME VARIES WITH THE DISTANCE OF THE ORIGIN FROM
  C**** THE NEAREST TERMINAL OF THE CARRIER. IF THIS DISTANCE IS
  C**** LESS THAN 75 MILES PICK-UP TIME IS ONE DAY, WHILE FOR
  C**** GREATER DISTANCES THE PICK-UP TIME IS TWO DAYS. IN THIS
  C**** PROGRAM WE HAVE ASSUMED PICK-UP TIME TO HAVE A UNIFORM
  C**** DISTRIBUTION BETWEEN ONE AND TWO DAYS.
  C**** TRANSIT TIME HAS BEEN FOUND FROM A LINEAR REGRESSION
  C**** MODEL BASED ON THE ACTUAL TRANSIT TIMES FOR LTL
  C**** FREIGHT FOR A LARGE CARRIER FROM THEIR TOLEDO TERMINAL.
  C**** PICTIM=UNFRM(1.,2.,1)
  241  XTIME=PICTIM+RNORM((2.47+YDIST*0.00266),1.159,1)
  242  CALL COLCT(XTIME,3)
  243  100 CONTINUE
  244  C    WRITE(NPRNT,*)'ZZ',LOCCST
  C    ENDIF
  245  C    WRITE(NPRNT,*)'TOTAL LOAD:',TLOAD

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ISN      246      101 CONTINUE
C**** SCHEDULE LOAD ARRIVAL FOR THE NEXT DAY
ISN      247      CALL SCHDL(1,1.0,TRIB)
ISN      248      RETURN
ISN      249      END
*STATISTICS*
*STATISTICS* SOURCE STATEMENTS = 210, PROGRAM SIZE = 65856 BYTES, PROGRAM NAME = ARVL - PAGE: 5.
***** END OF NO DIAGNOSTICS GENERATED.
***** END OF COMPILATION 2 *****
C
C
SUBROUTINE REVW
COMMON/SCOM1/ATTRIB(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
1,NCRDR,NPRNT,NRNR,NSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
COMMON/UCOM1/LOAD,TIN,TOUT,NS,LMAX,HOLD,TLCAST,IFLAG,TTIME,ORDR
1,LODYTD,NS1,NS2,NL,TTIME1,TTIME2
COMMON/VCOM1/NSL,CSTLT,LCCST,LHCST,TMPCST,LNCST,DIRCST,NDL,NL
1,LHCST2,LHDST2,LNCST1,LNCST2
REAL LCCST,TLCAST,LHCST,TMPCST,LNCST,LOAD,LHCST2,LHDST2,LNCST1
1,LNCST2
EQUIVALENCE(TLOAD,XX(1))
EQUIVALENCE(TLOAD1,XX(2))
EQUIVALENCE(TLOAD2,XX(3))
FORMAT(1X,'TOTAL LOAD:',F10.2,3X,F10.2)
999 FORMAT(1X,'TOTAL LOAD:',F10.2,3X,F10.2)
C**** SCHEDULE REVIEW AFTER SPECIFIC NUMBER OF SIMULATED DAYS
C**** AS GIVEN BY THE HOLDING TIME SPECIFIED.
C****
C**** CALL SCHDL(2,HOLD,TRIB)
C****
C**** COLLECT STATISTICS ON CONSOLIDATED LOAD GENERATED
C****
C**** ATTRIB(4)=TLOAD
C**** ATTRIB(7)=TLOAD1
C**** ATTRIB(8)=TLOAD2
C**** CALL COLCT(TLOAD,1)
C**** CALL COLCT(TLOAD1,6)
C**** CALL COLCT(TLOAD2,7)
C**** AFTER A STIPULATED HOLDING TIME AT THE CONSOLIDATION CENTER
C**** SCHEDULE A SHIPMENT FROM THE CONSOLIDATION
C**** CENTER
C
C
IF(TNOW.GT.0.) THEN
  CALL SCHDL(3,0.,TRIB)
  IFLAG=1
  ENDIF
  RETURN
END
SOURCE STATEMENTS = 22, PROGRAM SIZE = 1616 BYTES, PROGRAM NAME = REVIEW PAGE: 12.
*STATISTICS* NO DIAGNOSTICS GENERATED.
*STATISTICS* COMPILATION 3 *****
***** END OF *...1.....2.....3.....4.....5.....6.....7.....8
C****

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C****
C****
1  SUBROUTINE SHIP
2  COMMON/SCOM1/ATTRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
3  1,NCNDR,NPRNT,NRUN,NNSEI,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
4  1,COMMON/UCOM1/LOAD,TIN,TOUT,NS,LMAX,HOLD,TLCOST,TFLAG,TTIME,ORDR
5  1,LODYTD,NS1,NS2,NLT,TTIME1,TTIME2
6  1,COMMON/VCOM1/NSL,CSLTL,LOCCST,LHCOST,IMPCST,LNCOST,DIRCST,NDL,NL
7  1,LHCST2,LHDST2,LNCST1,LNCST2
8  1,COMMON/WCOM1/LRAT(300,10),LRATE,LTLRAT(300,10),LRATE,DIST(300,3)
9  1,XDIST,XTIME,DIST2(300,5),YDIST,LHDIST,DIST3(300,3)
10 1,COMMON/WCOM2/CZIP,CZIP2,DZIP,MAXD,LFACTR,OFACTR,MILPTR,NCNTR
11 1,COMMON/WCOM3/SUMPRD,SUMTIM,SUMTM1,SUMTM2
12 1,COMMON/WCOM5/TLRATE(50,10)
13 REAL CZIP,DZIP,MAXD,LFACTR,OFACTR,DIST,DIST2,XDIST,YDIST,LHDIST
14 REAL LRAT,LRATE,LOAD,LTLRAT,LTRATE,LODYTD,DIST3,CZIP2,LNCST1,LNCST2
15 REAL LOCCST,TLCOST,LHCOST,IMPCST,LHCST2,LHDST2,TCST1,TCST2
16 1,LRATE1,LRATE2,TLRATE
17 EQUIVALENCE(TLOAD,XX(1))
18 EQUIVALENCE(TLOAD1,XX(2))
19 EQUIVALENCE(TLOAD2,XX(3))
20 INITIALIZATION OF LOCAL VARIABLES
21 TCST1=0.
22 TCST2=0.
23 ITLLOAD=0
24 ITLORD1=0
25 ITLORD2=0
26 WRITE(NPRNT,*)'*****LHCST2',LHCST2
27 DETERMINE HOW MANY TRUCKLOAD SHIPMENTS TO BE MADE
28 C**** ALSO DETERMINE IF TRUCK-LOAD(TL) SHIPMENT IS JUSTIFIED IF
29 C**** TOTAL CONSOLIDATED LOAD DURING THE HOLDING TIME IS LESS
30 C**** THAN THE TRUCK-LOAD QUANTITY
31 C**** IF CASE= TWO CONSOLIDATION CENTERS, GO TO 200
32 IF(NCNTR.GT.1) GO TO 200
33 ITLLOAD=INT(TLOAD)
34 ILMAX=INT(ILMAX)
35 LTMP=MOD(ITLOAD,ILMAX)
36 TABLE LOOKUP TO FIND THE PROPER LINEHAUL RATE(LTL) BETWEEN
37 CONSOLIDATION CENTER AND FINAL DESTINATION.
38 DO 170 NN=1,24
39 IF(LRAT(NN,1).EQ.CZIP.AND.LRAT(NN,2).EQ.DZIP) THEN
40 IF(LTMP.LT.500) LRATE=LRAT(NN,4)
41 IF(LTMP.GE.500.AND.LTMP.LT.1000) LRATE=LRAT(NN,5)
42 IF(LTMP.GE.1000.AND.LTMP.LT.2000.) LRATE=LRAT(NN,6)
43 IF(LTMP.GE.2000.AND.LTMP.LT.5000.) LRATE=LRAT(NN,7)
44 IF(LTMP.GE.5000.AND.LTMP.LT.10000.) LRATE=LRAT(NN,8)
45 IF(LTMP.GE.10000.) LRATE=LRAT(NN,9)
46 IF((LTMP*LRATE/100.).LT.LRAT(NN,3)) LRATE=LRAT(NN,3)
47 ENDIF
48 170 CONTINUE
49 C WRITE(NPRNT,*)'WHOOH',LRATE,CZIP,DZIP
50

```

```

C****
C**** FINDING APPROPRIATE LINE-HAUL COST PER TRUCK-LOAD SHIPMENT
C**** FROM A TRUCK-LOAD RATE MATRIX
DO 75 N=1,24
  IF (TLRATE(N,1).EQ.CZIP .AND. TLRATE(N,2).EQ.DZIP) THEN
    LHCOST=TLRATE(N,5)
    LHDIST=TLRATE(N,3)
    WRITE(NPRNT,*) 'LHCOST', LHCOST, 'LHDIST', LHDIST
  C
  75 CONTINUE
  IF (TLOAD.GT.0.) THEN
    IF (TLOAD.LT.LMAX) THEN
      TMPGST=(TLOAD*LRATE)/10000.
      NS=NS+1
      WRITE(NPRNT,*) 'FIRST', TMPGST
      IF (LHCOST.LT. TMPGST) THEN
        TMPGST=LHCOST
      ENDIF
    ELSE
      IF (LHCOST .LE. (MOD(ITLOAD,ILMAX)*LRATE/10000.)) THEN
        TMPGST=INT(TLOAD/LMAX+.99)*LHCOST
        NS=NS+INT(TLOAD/LMAX+.99)
        NTL=NTL+INT(TLOAD/LMAX+.99)
      ELSE
        TMPGST=INT(TLOAD/LMAX)*LHCOST+(MOD(ITLOAD,ILMAX)*LRATE)/10000.
        NS=NS+INT(TLOAD/LMAX)+1
        NS=NS+1
        NTL=NTL+INT(TLOAD/LMAX)
      ENDIF
      WRITE(NPRNT,*) 'SECOND', TMPGST
    ENDIF
  ENDIF
  C
  C****
  C**** LNCOST IS THE LINE-HAUL COST FROM CONSOLIDATION CENTER TO
  C**** THE FINAL DESTINATION
  C**** LNCOST=LNCOST+TMPGST
  C**** WRITE(NPRNT,*) 'LINE-HAUL COST', LNCOST
  C**** AFTER CONCLUSION OF COST CALCULATION FOR ONE CONSOLIDATION
  C**** CENTER CASE GO TO 285 FOR TRANSIT TIME CALCULATION FOR
  C**** ONE CONSOLIDATION CENTER.
  C**** GOTO 285
  C**** TWO CONSOLIDATION CENTER CASE
  200 ITLOD1=INT(TLOAD1)
  ITLOD2=INT(TLOAD2)
  ILMAX=INT(LMAX)
  LTMP1=MOD(ITLOD1,ILMAX)
  LTMP2=MOD(ITLOD2,ILMAX)
  C**** TABLE LOOKUP TO FIND PROPER LTL LINEHAUL RATE BETWEEN
  C**** CONSOLIDATION CENTER AND DESTINATION.
  C**** DO 270 I=1,24
  IF (LRAT(I,1).EQ.CZIP .AND. LRAT(I,2).EQ.DZIP) THEN

```

```

75 ISN IF(LTMP1.LT.500) LRATE1=LRAT(1,4)
77 ISN IF(LTMP1.GE.500 .AND. LTMP1.LT.1000) LRATE1=LRAT(1,5)
79 ISN IF(LTMP1.GE.1000..AND. LTMP1.LT.2000.) LRATE1=LRAT(1,6)
81 ISN IF(LTMP1.GE.2000..AND. LTMP1.LT.5000.) LRATE1=LRAT(1,7)
83 ISN IF(LTMP1.GE.5000..AND. LTMP1.LT.10000.) LRATE1=LRAT(1,8)
85 ISN IF(LTMP1.GE.10000.) LRATE1=LRAT(1,9)
87 ISN IF((LTMP1*LRATE/100.) .LT. LRAT(1,3)) LRATE1=LRAT(1,3)
89 ISN ENDIF
90 ISN 270 CONTINUE
C WRITE(NPRNT,*)'WHOO!', LRATE1,CZIP,DZIP
C***** FIND CONSOLIDATED LOAD SHIPMENT COST
C*****
91 ISN DO 80 N=1,24
92 ISN IF(TLRATE(N,1).EQ.CZIP .AND. TLRATE(N,2).EQ.DZIP) THEN
93 ISN LHCOST=TLRATE(N,5)
94 ISN LHDIST=TLRATE(N,3)
C WRITE(NPRNT,*)'LHCOST1',LHCOST,'LHDIST1',LHDIST
ENDIF
95 ISN IF(TLRATE(N,1).EQ.CZIP2 .AND. TLRATE(N,2).EQ.DZIP) THEN
96 ISN LHCST2=TLRATE(N,5)
97 ISN LHDST2=TLRATE(N,3)
C WRITE(NPRNT,*)'LHCST2',LHCST2,'LHDST2',LHDST2
ENDIF
99 ISN 80 CONTINUE
100 ISN C***** FIND CONSOLIDATED LOAD SHIPMENT COST
IF(TLOAD1.GT.0.) THEN
101 ISN IF(TLOAD1.LT.LMAX) THEN
102 ISN TCST1=(TLOAD1*LRATE1)/10000.
103 ISN NS1=NS1+1
104 ISN C WRITE(NPRNT,*)'FIRST',TCST1
IF(LHCOST .LT. TCST1) THEN
105 ISN TCST1=LHCOST
106 ISN ENDIF
ELSE
107 ISN IF(LHCOST .LE. (MOD(ITLOD1,ILMAX)*LRATE1/10000.)) THEN
108 ISN TCST1=INT((TLOAD1/LMAX+.99999)*LHCOST)
109 ISN NS1=NS1+INT((TLOAD1/LMAX+.99999)
110 ISN NTL=NTL+INT((TLOAD1/LMAX+.99999)
ELSE
111 ISN TCST1=INT((TLOAD1/LMAX)*LHCOST+(MOD(ITLOD1,ILMAX)*LRATE1)/10000.
112 ISN NS1=NS1+INT((TLOAD1/LMAX)+1)
113 ISN NS1=NS1+1
114 ISN NTL=NTL+INT((TLOAD1/LMAX)
115 ISN C WRITE(NPRNT,*)'SECOND',TCST1
ENDIF
116 ISN ENDIF
117 ISN ENDIF
118 ISN C WRITE(NPRNT,*)'TLOAD1',TLOAD1,'TCST1',TCST1,'NS1',NS1
C***** LNCST1 IS THE LINE-HAUL COST FROM CONSOLIDATION CENTER 1 TO
C***** THE FINAL DESTINATION
LNCST1=LNCST1+TCST1
119 ISN

```

```

C**** FIND CONSOLIDATED LOAD SHIPMENT COST FOR CONSOLIDATION
C****
C**** CENTER 2
DO 280 J=1,24
  IF (LRAT(J,1).EQ.CZIP2 .AND. LRAT(J,2).EQ.DZIP) THEN
    IF (LTMP2.LT.500) LRATE2=LRAT(J,4)
    IF (LTMP2.GE.500 .AND. LTMP2.LT.1000) LRATE2=LRAT(J,5)
    IF (LTMP2.GE.1000 .AND. LTMP2.LT.2000) LRATE2=LRAT(J,6)
    IF (LTMP2.GE.2000 .AND. LTMP2.LT.5000) LRATE2=LRAT(J,7)
    IF (LTMP2.GE.5000 .AND. LTMP2.LT.10000) LRATE2=LRAT(J,8)
    IF (LTMP2.GE.10000) LRATE2=LRAT(J,9)
    IF ((LTMP2*LRATE2/100.) .LT. LRAT(J,3)) LRATE2=LRAT(J,3)
  ENDIF
280 CONTINUE
C**** WRITE(NPRNT,*)'WHOOH', LRATE2,CZIP2,DZIP
  IF (TLOAD2.GT.0.) THEN
    IF (TLOAD2.LT.LMAX) THEN
      TCST2=(TLOAD2*LRATE2)/10000.
      NS2=NS2+1
      WRITE(NPRNT,*)'SECOND', TCST2, 'LHCST2', LHCST2
      IF (LHCST2.LT. TCST2) THEN
        TCST2=LHCST2
      ENDIF
    ELSE
      IF (LHCST2.LE. (MOD(1TLOAD2,ILMAX)*LRATE2/10000.)) THEN
        TCST2=INT((TLOAD2/LMAX+.99999)*LHCST2)
        NS2=NS2+INT((TLOAD2/LMAX+.99999)
        NTL=NTL+INT((TLOAD2/LMAX+.99999)
      ELSE
        TCST2=INT((TLOAD2/LMAX)*LHCST2+(MOD(1TLOAD2,ILMAX)*LRATE2)/10000.
        NS2=NS2+INT((TLOAD2/LMAX)+1
        NTL=NTL+INT((TLOAD2/LMAX)
      ENDIF
    ENDIF
  ENDIF
C**** WRITE(NPRNT,*)'TLOAD2', TLOAD2, 'TCST2', TCST2, 'NS2', NS2
C**** LNCST2 IS THE LINE-HAUL COST FROM CONSOLIDATION CENTER 2 TO
C**** THE FINAL DESTINATION
C**** IF (TCST2.LT. 0.) TCST2=0.
  LNCST2=LNCST2+TCST2
  LNCST=LNCST1+LNCST2
C**** WRITE(NPRNT,*)'LNCST2', LNCST2, 'TCST2', TCST2
C**** FIND TOTAL NUMBER OF CONSOLIDATED SHIPMENTS
  NS=NS1+NS2
C**** FIND TRANSIT TIME FOR CONSOLIDATED SHIPMENTS
C**** FOR CONSOLIDATION CENTER 1
  IF (TLOAD1.GT. 0.) THEN
    IF (CONSOLIDATED LOAD >= TRUCK LOAD, THEN TRANSIT TIME
    =LHDIST/(42*24) DAYS+LOCAL PICK-UP TIME
    IF (TLOAD1.GE.LMAX) TT=TT+LHDIST/(42.*24.)+1
  ENDIF

```

ISN 120

ISN 121

ISN 122

ISN 124

ISN 126

ISN 128

ISN 130

ISN 132

ISN 134

ISN 136

ISN 137

ISN 138

ISN 139

ISN 140

ISN 141

ISN 142

ISN 143

ISN 144

ISN 145

ISN 146

ISN 147

ISN 148

ISN 149

ISN 150

ISN 151

ISN 152

ISN 153

ISN 154

ISN 155

ISN 156

ISN 157

ISN 158

ISN 159

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C**** IF CONSOLIDATED LOAD < TRUCK LOAD, THEN TRANSIT TIME
C**** =2.47+0.00266*LHDIST+LOCAL PICK-UP TIME IN DAYS
C      IF (TLOAD1.LT.LMAX) TTIME1=2.47+LHDIST*0.00266+1
C      TTIME1=UNFRM((LHDIST/(42.*24.)), (2.47+LHDIST*0.00266), 1)+1
C      SUMTM1=SUMTM1+TTIME1
C      ENDIF
C**** FIND TRANSIT TIME FOR DISPATCHES THROUGH
C**** SECOND CONSOLIDATION CENTER
C      IF (TLOAD2.GT.0.) THEN
C**** IF CONSOLIDATED LOAD >= TRUCK LOAD, THEN TRANSIT TIME
C**** =LHDST2/((42*24) DAYS+LOCAL PICK-UP TIME
C      IF (TLOAD2.GE.LMAX) TTIME2=LHDST2/((42.*24.))+1
C**** IF CONSOLIDATED LOAD < TRUCK LOAD, THEN TRANSIT TIME
C**** =2.47+0.00266*LHDIST+LOCAL PICK-UP TIME IN DAYS
C      IF (TLOAD2.LT.LMAX) TTIME2=2.47+LHDST2*0.00266+1
C      TTIME2=UNFRM((LHDST2/(42.*24.)), (2.47+LHDST2*0.00266), 1)+1
C      SUMTM2=SUMTM2+TTIME2
C      ENDIF
C      WRITE(NPRNT,*)'TIME1', TTIME1, 'TIME2', TTIME2
C      WRITE(NPRNT,*)'SUMTIME1', SUMTM1, 'SUMTIME2', SUMTM2
C      IF(NCNR.GT.1) GO TO 290
285 CONTINUE
C**** FIND TRANSIT TIME FOR ONE CONSOLIDATION CENTER
C**** CASE
C      WRITE(NPRNT,*)'CHECK', LNCOST
C      TOUT=TNOW
C**** IF CONSOLIDATED LOAD >= TRUCK LOAD, THEN TRANSIT TIME
C**** =LHDIST/((42*24) DAYS+LOCAL PICK-UP TIME
C      IF (TLOAD.GE.LMAX) TTIME=LHDIST/((42.*24.))+1
C**** IF CONSOLIDATED LOAD < TRUCK LOAD, THEN TRANSIT TIME
C**** =2.47+0.00266*LHDIST+LOCAL PICK-UP TIME IN DAYS
C      IF (TLOAD.LT.LMAX) TTIME=2.47+LHDIST*0.00266+1
C      TTIME=UNFRM((LHDIST/(42.*24.)), (2.47+LHDIST*0.00266), 1)+1
C      SUMTIM=SUMTIM+TTIME
C      WRITE(NPRNT,*)'TIME', TTIME, 'SUMTIME', SUMTIM
C      CONTINUE
290 CONTINUE
C**** SCHEDULE A RECEIPT
C      IF(FLAG.NE.1) RETURN
C      IF(NCNR.EQ.1) CALL SCHDL(4, TTIME, ATRIB)
C      IF(NCNR.GT.1) THEN
C          IF (TTIME1.GT.TTIME2) THEN
C              CALL SCHDL(4, TTIME2, ATRIB)
C          ELSE
C              CALL SCHDL(4, TTIME1, ATRIB)
C          ENDIF
C      ENDIF
C      TLOAD=0.
C      TLOAD1=0.
C      TLOAD2=0.
C      CALL SCHDL(4, TNOW, ATRIB)
C      RETURN
99

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ISN 180
*STATISTICS*
*STATISTICS*
***** END OF
1 .....2 .....3 .....4 .....5 .....6 .....7 .....8
END
SOURCE STATEMENTS = 158, PROGRAM SIZE = 11032 BYTES, PROGRAM NAME = SHIP PAGE: 13.
NO DIAGNOSTICS GENERATED.
***** COMPILATION 4 *****
C
SUBROUTINE REOPT
COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
1,NCNDR,NPRNT,NRUN,NSET,NTAPE,SSL(100),SSL(100),TNEXT,TNOW,XX(100)
COMMON/UCOM1/LOAD,TIN,TOUT,NS,LMAX,HOLD,TLCOST,IFLAG,TTIME,ORDR
1,LODYTD,NS1,NS2,NIL,TTIME1,TTIME2
COMMON/VCOM1/NSL,CSLIL,LOCST,LHCOST,TPCST,LNCOST,DIRCST,NDL,NL
1,LHCST2,LHDS2,LNCST1,LNCST2
COMMON/WCOM1/LRAT(300,10),LRATE,LTLRAT(300,10),LTRATE,DIST(300,3)
1,XDIST,XTIME,DIST2(300,5),YDIST,LHDIST,DIST3(300,3)
COMMON/WCOM2/CZ1P,CZ1P2,DZ1P,MAXD,LFACTR,OFACTR,MILPTR,NCNTR
COMMON/WCOM3/SUMPRD,SUMTIM,SUMTM1,SUMTM2
COMMON/WCOM4/SUMTMP,NSLTMP,NSLTMP,TMPTIM,NSTMP,TMPTM1,TMPTM2
REAL LOCST,TLCOST,LHCOST,TPCST,TPCST,LRAT,LRATE,LTLRAT,LTRATE
1,DIST,DIST2,XDIST,YDIST,LHDIST,LODYTD,LHCST2,LHDS2,LNCST1,LNCST2
EQUIVALENCE(TLOAD,XX(1))
EQUIVALENCE(TLOAD1,XX(2))
EQUIVALENCE(TLOAD2,XX(3))
IFLAG=0
TOTIM=0.
TOTIM1=0.
TOTIM2=0.
C**** CALCULATE AVERAGE TOTAL TIME IN SYSTEM
SUMTMP=SUMPRD-SUMTMP
NSLTMP=NSL-NSLTMP
TMPTIM=SUMTIM-TMPTIM
TMPTM1=SUMTM1-TMPTM1
TMPTM2=SUMTM2-TMPTM2
NSTMP=NS-NSTMP
WRITE(NPRNT,*)'SUMTMP',SUMTMP,'TMPTIM',TMPTIM,'NSLTMP',NSLTMP
WRITE(NPRNT,*)'NSTMP',NSTMP,'TMPTM1',TMPTM1,'TMPTM2',TMPTM2
1,'SUMTM1',SUMTM1,'SUMTM2',SUMTM2
IF(NSLTMP.GT.0) THEN
IF(NCNR.EQ.1) THEN
TOTIM=SUMTMP/NSLTMP+TTIME
WRITE(NPRNT,*)'TOTIM*',TOTIM
ENDIF
IF(NCNR.EQ.2) THEN
TOTIM1=(SUMTMP/NSLTMP)+TTIME1
TOTIM2=(SUMTMP/NSLTMP)+TTIME2
ENDIF
ENDIF
C
WRITE(NPRNT,*)'TOTIM',TOTIM,'TOTIM1',TOTIM1,'TOTIM2',TOTIM2
C**** COLLECT STATISTICS ON TOTAL TIME FOR ALL CONSOLIDATED
C**** SHIPMENTS

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32 IF(NCINTR.GT.1) GO TO 5
33 IF(TOTIM.GT. 0.)CALL COLCT(TOTIM,5)
35 IF(NCINTR.EQ.1) GO TO 15
36 IF(TOTIM1.GT.0.)CALL COLCT(TOTIM1,5)
38 IF(TOTIM2.GT.0.)CALL COLCT(TOTIM2,5)
15 CONTINUE
40 SUMTMP=SUMPRD
41 NSLTMP=NSL
42 TMPTIM=SUMTIM
43 TMPTM1=SUMTM1
44 TMPTM2=SUMTM2
45
C**** AFTER DISPATCH OF CONSOLIDATED LOAD SET VALUES OF CONSOLIDATED
C**** LOAD AT EACH CENTER TO ZERO.
46 TLOAD=0.
47 TLOAD1=0.
48 TLOAD2=0.
49 NSTMP=NS
50
10 RETURN
51 END
51
*STATISTICS*
*STATISTICS*
***** END OF
C
1 SUBROUTINE EVENT(1)
2 GO TO (1,2,3,4,5),1
3 CALL ARVL
4 RETURN
5 CALL REVIEW
6 RETURN
7 CALL SHIP
8 RETURN
9 CALL RECPT
10 RETURN
11 CALL REPORT
12 RETURN
13 END
*STATISTICS*
*STATISTICS*
***** END OF
C
SOURCE STATEMENTS = 48, PROGRAM SIZE = 3318 BYTES, PROGRAM NAME = RECPT PAGE: 18.
NO DIAGNOSTICS GENERATED.
***** END OF COMPILATION 5 *****
C
SOURCE STATEMENTS = 13, PROGRAM SIZE = 702 BYTES, PROGRAM NAME = EVENT PAGE: 20.
NO DIAGNOSTICS GENERATED.
***** END OF COMPILATION 6 *****
C
SUBROUTINE INTLC
COMMON/SCOM1/ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA, MSTOP, NCLNR
1, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(100), SSL(100), TNEXT, TNOW, XX(100)
COMMON/UCOM1/LOAD, TIN, TOUT, NS, LMAX, HOLD, TLCOST, IFLAG, TTIME, ORDR
1, LODYTD, NS1, NS2, NTL
COMMON/VCOM1/NSL, CSTLTL, LOCCST, LHCCOST, TMCOST, LNCOST, DIRCST, NDL, NL
1, LHCST2, LHDST2, LNCST1, LNCST2
COMMON/WCOM2/CZ1P, CZ1P2, DZ1P, MAXD, LFACR, OFACR, MILPTR, NCNTR
COMMON/WCOM3/SUMPRD, SUMTIM, SUMTM1, SUMTM2

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7      COMMON/WCOM4/SUMTMP, NSLTMP, TMPTIM, NSTMP, TMPTM1, TMPTM2
8      REAL CZIP, DZIP, MAXD, LFACTR, OFACTR, CZIP2, LNCST1, LNCST2
9      REAL LOCCST, TLCST, LHCST, LHCST, TMPCST, LNCST, LHCST2, LHDST2
10     EQUIVALENCE(TLOAD, XX(1))
11     EQUIVALENCE(TLOAD1, XX(2))
12     EQUIVALENCE(TLOAD2, XX(3))
13     LOAD=0.
14     TTIME=0.
15     TTIME1=0.
16     TTIME2=0.
17     TMPTIM=0.
18     TMPTM1=0.
19     TMPTM2=0.
20     SUMTIM=0.
21     SUMTM1=0.
22     SUMTM2=0.
23     SUMPRD=0.
24     SUMTMP=0.
25     NSLTMP=0
26     TLOAD=0.
27     TLOAD1=0.
28     TLOAD2=0.
29     LODYTD=0.
30     TOUT=0
31     NS=0
32     NS1=0
33     NS2=0
34     NSTMP=0
35     IFLAG=0
36     LMAX=16000.
37     HOLD=5.0
38     NL=0
39     NSL=0
40     NDL=0
41     DIRCST=0.
42     CSTLTL=0.
43     TLCST=0.
44     LOCCST=0.
45     TMPCST=0.
46     LNCST=0.
47     LNCST1=0.
48     LNCST2=0.
49     LHCST=0.
50     LHCST2=0.
51     C**** INITIALIZE ATRIB ARRAY
52     DO 10 I=1,8
53     ATRIB(I)=0.
54     10 CONTINUE
55     C**** SCHEDULE FIRST LOAD ARRIVAL EVENT
56     CALL SCHDL(1.0.,ATRIB)
57     C**** SCHEDULE FIRST REVIEW EVENT

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ISN 54      CALL SCHDL(2,0.,ATTRIB)
ISN 55      C**** SCHEDULE FIRST REPORT EVENT
ISN 56      CALL SCHDL(5,125.,ATTRIB)
ISN 57      RETURN
ISN 57      END
*STATISTICS* SOURCE STATEMENTS = 57, PROGRAM SIZE = 3008 BYTES, PROGRAM NAME = INTLC
*DIAGNOSTICS* NO DIAGNOSTICS GENERATED.
***** END OF C
C
ISN 1        SUBROUTINE REPORT
ISN 2        COMMON/SCOM1/ATTRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
ISN 3        1,NCRDR,NPRNT,NRUN,NNSEI,NTAPE,SSL(100),SSL(100),TNEXT,TNOW,XX(100)
ISN 4        COMMON/UCOM1/LOAD,TIN,TOUT,NS,LMAX,HOLD,TLCOST,IFLAG,ITIME,ORDR
ISN 5        1,LODYTD,NS1,NS2,NL
ISN 6        COMMON/VCOM1/NSL,CSTLTL,LOCCST,LHCOST,IMPCST,LNCCST,DIRCST,NDL,NL
ISN 7        1,LHCST2,LHDST2,LNCST1,LNCST2
ISN 8        COMMON/WCOM2/CZIP,CZIP2,DZIP,MAXD,LFACTR,OFACTR,MILPTR,NCNTR
ISN 9        COMMON/WCOM3/SUMPRD,SUMTIM
ISN 10       REAL CZIP,DZIP,MAXD,LFACTR,OFACTR,LODYTD,CZIP2,LHDST2
ISN 11       REAL LOCCST,TLCOST,LHCOST,IMPCST,LNCCST,CSTLTL,DIRCST,LHCST2
ISN 12       1,LNCST1,LNCST2
ISN 13       C**** SCHEDULE NEXT REPORT
ISN 14       CALL SCHDL(5,125.,ATTRIB)
ISN 15       C**** CALCULATING COST OF CONSOLIDATED SHIPMENT SCHEME
ISN 16       C**** TOTAL COST=LINE-HAUL COST FROM CONSOLIDATION CENTER TO THE
ISN 17       C**** DESTINATION + (CONSOLIDATION COST+ LOCAL CARTAGE)+ DIRECT
ISN 18       C**** DISPATCH COST WHEN SHIPMENTS ARE NOT ROUTED THROUGH THE
ISN 19       C**** CONSOLIDATION CENTER BECAUSE OF DISTANCE.
ISN 20       TLCCST=LNCOST+LOCCST+DIRCST
ISN 21       C**** FINDING THE WEIGHTED AVERAGE TIME IN SYSTEM UNDER CONSOLIDATION
ISN 22       SCHEME
ISN 23       IF(NSL.GT.0) THEN
ISN 24         AVE=SUMPRD/NSL
ISN 25         TOTIM=SUMPRD/NSL+ATTRIB(5)+1
ISN 26       ENDIF
ISN 27       WRITE(NPRNT,*)
ISN 28       WRITE(NPRNT,3)
ISN 29       WRITE(NPRNT,2) TNOW
ISN 30       WRITE(NPRNT,3)
ISN 31       WRITE(NPRNT,*)
ISN 32       WRITE(NPRNT,*)
ISN 33       IF(NCNTR.EQ.1) THEN
ISN 34         WRITE(NPRNT,9) CZIP
ISN 35       ENDIF
ISN 36       IF(NCNTR.EQ.2) THEN
ISN 37         WRITE(NPRNT,91) CZIP
ISN 38         WRITE(NPRNT,92) CZIP2
ISN 39       ENDIF
ISN 40       WRITE(NPRNT,11) DZIP
ISN 41       WRITE(NPRNT,4) HOLD

```

```

30      WRITE(NPRNT,1) MAXD
31      WRITE(NPRNT,7) LFACTR
32      WRITE(NPRNT,8) OFACTR
33      WRITE(NPRNT,6) NL
34      IF(NCNR.EQ.1) THEN
35          WRITE(NPRNT,5) NS
36          WRITE(NPRNT,52) NTL
37      ENDIF
38      IF(NCNR.EQ.2) THEN
39          WRITE(NPRNT,55) NS1
40          WRITE(NPRNT,57) NS2
41          WRITE(NPRNT,52) NTL
42      ENDIF
43      WRITE(NPRNT,15) NSL
44      WRITE(NPRNT,40) NDL
45      WRITE(NPRNT,10) TLCOST
46      WRITE(NPRNT,60) LNCOST
47      WRITE(NPRNT,50) DIRCST
48      WRITE(NPRNT,20) LOCCST
49      WRITE(NPRNT,30) CSTLTL
50      WRITE(NPRNT,70) AVE
51      WRITE(NPRNT,80) TOTIM
52      WRITE(NPRNT,85) LODYTD
53      WRITE(NPRNT,*)
54      WRITE(NPRNT,*)
55      WRITE(NPRNT,*)
56      FORMAT(35X,'CONSOLIDATION CENTER ZIP CODE: ',F5.0)
57      FORMAT(35X,'CONSOL CENTER 1 ZIP CODE: ',F5.0)
58      FORMAT(35X,'CONSOL CENTER 2 ZIP CODE: ',F5.0)
59      FORMAT(35X,'DESTINATION ZIP CODE: ',F5.0)
60      FORMAT(35X,'MAXIMUM DISTANCE OF ORIGIN FROM CONSOL CENTER: ',F5.0
61      1,' MILES')
62      FORMAT(44X,'* SUMMARY FOR A PERIOD OF: ',F5.0,2X,'DAYS *')
63      FORMAT(44X,'*****')
64      FORMAT(35X,'HOLDING TIME AT CONSOLIDATION CENTER = ',F5.0,' DAYS')
65      FORMAT(35X,'NUMBER OF CONSOLIDATED SHIPMENTS LTL MADE= ',15)
66      FORMAT(35X,'NUMBER OF TRUCK-LOAD SHIPMENTS MADE= ',15)
67      FORMAT(35X,'NO. OF CONSOLIDATED SHIPMENTS LTL THRU FIRST CC= ',15)
68      FORMAT(35X,'NO. OF CONSOLIDATED SHIPMENTS LTL THRU SECOND CC= ',15)
69      FORMAT(35X,'NUMBER OF LOADS ORIGINATING IN THE REGION = ',18)
70      FORMAT(35X,'LOAD FACTOR: ',F6.3)
71      FORMAT(35X,'ORDER NUMBER FACTOR: ',F5.2)
72      FORMAT(35X,'TOTAL COST UNDER CONSOLIDATION SCHEME = ',F14.2)
73      FORMAT(35X,'NUMBER OF LOCAL DELIVERIES MADE TO CONSOL CENTER= ',18)
74      FORMAT(35X,'TOTAL LOCAL DELIVERIES COST= ',F14.2)
75      FORMAT(35X,'LTL SHIPMENT COST NO CONSOLIDATION= ',F14.2)
76      FORMAT(35X,'NUMBER OF DIRECT DISPATCHES UNDER CONSOLIDATION = ',15)
77      FORMAT(35X,'DIRECT DISPATCH COST UNDER CONSOL SCHEME = ',F14.2)
78      FORMAT(35X,'LINE-HAUL COST UNDER CONSOLIDATION SCHEME = ',F14.2)
79      FORMAT(35X,'WEIGHTED AVERAGE TIME IN CONSOLIDATION CENTER = ',F8.2)
80      FORMAT(35X,'WTD. AVERAGE TIME FROM ORIGIN TO DESTINATION = ',F8.2)

```



```

32      WRITE(NPRNT,8) OFACTR
33      WRITE(NPRNT,6) NL
34      IF(NCNR.EQ.1) THEN
35          WRITE(NPRNT,5) NS
36          WRITE(NPRNT,52) NTL
37      ENDIF
38      IF(NCNR.EQ.2) THEN
39          WRITE(NPRNT,55) NS1
40          WRITE(NPRNT,57) NS2
41          WRITE(NPRNT,52) NTL
42      ENDIF
43      WRITE(NPRNT,15) NSL
44      WRITE(NPRNT,40) NDL
45      WRITE(NPRNT,10) TLCOST
46      WRITE(NPRNT,60) LNCOST
47      WRITE(NPRNT,20) DIRCST
48      WRITE(NPRNT,20) LOCCST
49      WRITE(NPRNT,30) CSILTL
50      WRITE(NPRNT,70) AVE
51      WRITE(NPRNT,80) TOTIM
52      WRITE(NPRNT,85) LODYTD
53      WRITE(NPRNT,*)
54      WRITE(NPRNT,*)
55      WRITE(NPRNT,*)
56      FORMAT(35X,'CONSOLIDATION CENTER ZIP CODE: ',F5.0)
57      FORMAT(35X,'CONSOL CENTER 1 ZIP CODE: ',F5.0)
58      FORMAT(35X,'CONSOL CENTER 2 ZIP CODE: ',F5.0)
59      FORMAT(35X,'DESTINATION ZIP CODE: ',F5.0)
60      FORMAT(35X,'MAXIMUM DISTANCE OF ORIGIN FROM CONSOL CENTER: ',F5.0
61      ' MILES')
62      *****
63      FORMAT(44X,'*****')
64      FORMAT(35X,'HOLDING TIME AT CONSOLIDATION CENTER = ',F5.0,' DAYS')
65      FORMAT(35X,'NUMBER OF CONSOLIDATED LTL SHIPMENTS MADE = ',15)
66      FORMAT(35X,'NUMBER OF TRUCK-LOAD SHIPMENTS MADE = ',15)
67      FORMAT(35X,'NO. OF CONSOLIDATED SHIPMENTS LTL THRU FIRST CC= ',15)
68      FORMAT(35X,'NO. OF CONSOLIDATED SHIPMENTS LTL THRU SECOND CC= ',15)
69      FORMAT(35X,'NUMBER OF LOADS ORIGINATING IN THE REGION = ',18)
70      FORMAT(35X,'LOAD FACTOR: ',F5.2)
71      FORMAT(35X,'ORDER NUMBER FACTOR: ',F5.2)
72      FORMAT(35X,'TOTAL COST UNDER CONSOLIDATION SCHEME = ',F14.2)
73      FORMAT(35X,'NUMBER OF LOCAL DELIVERIES MADE TO CONSOL CENTER = ',
74      18)
75      FORMAT(35X,'TOTAL LOCAL DELIVERIES COST = ',F14.2)
76      FORMAT(44X,'* SUMMARY FOR A PERIOD OF: ',F5.0,2X,' DAYS *')
77      FORMAT(35X,'LTL SHIPMENT COST NO CONSOLIDATION = ',F14.2)
78      FORMAT(35X,'NUMBER OF DIRECT DISPATCHES UNDER CONSOLIDATION = ',15)
79      FORMAT(35X,'DIRECT DISPATCH COST UNDER CONSOL SCHEME = ',F14.2)
80      FORMAT(35X,'LINE-HAUL COST UNDER CONSOLIDATION SCHEME = ',F14.2)
81      FORMAT(35X,'WEIGHTED AVERAGE TIME IN CONSOLIDATION CENTER = ',F8.2)
82      FORMAT(35X,'WTD. AVERAGE TIME FROM ORIGIN TO DESTINATION = ',F8.2)
83      FORMAT(35X,'TOTAL LOAD RECEIVED YEAR TO DATE: ',F14.2,' POUNDS')

```


LIMITS,2,8,10999;
 PRIORITY/NCLNR,LVF(7);
 SEEDS,4367651(1),6121137(2);
 STAT,1,CONSOLIDTD LOAD,20/0/5000;
 STAT,2,LOADS PER DAY,20/0/1;
 STAT,3,LTL TRNST TIME,10/0/1;
 STAT,4,AVG TIME IN CC,10/0/1;
 STAT,5,AVG TIME IN SYS,10/0/1;
 STAT,6,TLOAD CENTER 1;
 STAT,7,TLOAD CENTER 2;
 INIT,0,250;
 MONTR,TRACE,0,20,ATRIB(4),ATRIB(7),ATRIB(8);
 MONTR,SUMRY,125,125;
 FIN;

S L A M I I E C H O R E P O R T

BY PRABIR BAGCHI

SIMULATION PROJECT CONSOLIDATION MODEL

RUN NUMBER 1 OF 1

DATE 10/29/1985

SLAM II VERSION OCT 85

GENERAL OPTIONS

PRINT INPUT STATEMENTS (ILIST): YES
 PRINT ECHO REPORT (IECHO): YES
 EXECUTE SIMULATIONS (IXQT): YES
 WARN OF DESTROYED ENTITIES: YES
 PRINT INTERMEDIATE RESULTS HEADING (IPIRH): YES
 PRINT SUMMARY REPORT (ISMRY): YES

LIMITS ON FILES

MAXIMUM NUMBER OF USER FILES (MFILS): 2
 MAXIMUM NUMBER OF USER ATTRIBUTES (MATR): 8
 MAXIMUM NUMBER OF CONCURRENT ENTRIES (MNTRY): 10999

FILE SUMMARY

FILE NUMBER	INITIAL ENTRIES	RANKING CRITERION
1	0	FIFO
2	0	FIFO

STATISTICS BASED ON OBSERVATIONS

COLCT NUMBER	COLLECTION MODE	IDENTIFIER	HISTOGRAM SPECIFICATIONS NCEL HLOW HUID
1	EVENT	CONSOLIDTD LOAD	20 0.000E+00 0.500E+04
2	EVENT	LOADS PER DAY	20 0.000E+00 0.100E+01
3	EVENT	LTL TRNST TIME	10 0.000E+00 0.100E+01
4	EVENT	AVG TIME IN CC	10 0.000E+00 0.100E+01
5	EVENT	AVG TIME IN SYS	10 0.000E+00 0.100E+01
6	EVENT	TLOAD CENTER 1	
7	EVENT	TLOAD CENTER 2	

RANDOM NUMBER STREAMS

STREAM NUMBER	SEED VALUE	REINITIALIZATION OF STREAM
1	4367651	NO
2	6121137	NO
3	1145661099	NO
4	1835732737	NO
5	794161987	NO
6	1329531353	NO
7	200496737	NO
8	633816299	NO
9	1410143363	NO
10	1282538739	NO

INITIALIZATION OPTIONS

BEGINNING TIME OF SIMULATION (TTBEG): 0.0000E+00
ENDING TIME OF SIMULATION (TTFIN): 0.2500E+03
STATISTICAL ARRAYS CLEARED (JJCLR): YES
VARIABLES INITIALIZED (JJVAR): YES
FILES INITIALIZED (JJFIL): YES

NSET/QSET STORAGE ALLOCATION

DIMENSION OF NSET/QSET (NNSET): 150000
WORDS ALLOCATED TO FILING SYSTEM: 131988
WORDS ALLOCATED TO VARIABLES: 12304
WORDS AVAILABLE FOR PLOTS/TABLES: 5708

INPUT ERRORS DETECTED: 0

EXECUTION WILL BE ATTEMPTED

INTERMEDIATE RESULTS

SLAM II TRACE BEGINNING AT TNOW= 0.0000E+00

NODE ARRIVAL				ACTIVITY SUMMARY		
-----				-----		
TNOW	JEVNT	LABEL	TYPE	INDEX	DURATION	END NODE

0.1000E+01	1					
0.2000E+01	1					
0.3000E+01	1					
0.4000E+01	1					
0.5000E+01	1					
0.6000E+01	1					
0.7000E+01	2					
	1					
	3					
0.8000E+01	1					
0.9000E+01	1					
0.1000E+02	1					
0.1100E+02	1					
0.1200E+02	1					
0.1300E+02	1					
0.1400E+02	2					
	4					
	1					
	3					
0.1500E+02	1					
0.1600E+02	1					
0.1700E+02	1					
0.1800E+02	1					
0.1900E+02	1					
0.2000E+02	1					
0.2000E+02	1					
END OF TRACE						

* SUMMARY FOR A PERIOD OF: 125. DAYS *

CONSOLIDATION CENTER ZIP CODE: 606.
DESTINATION ZIP CODE: 230.
HOLDING TIME AT CONSOLIDATION CENTER = 7. DAYS

MAXIMUM DISTANCE OF ORIGIN FROM CONSOL CENTER: 100. MILES
 LOAD FACTOR: 1.000
 ORDER NUMBER FACTOR: 1.00
 NUMBER OF LOADS ORIGINATING IN THE REGION = 366
 NUMBER OF CONSOLIDATED SHIPMENTS LTL MADE= 14
 NUMBER OF TRUCK-LOAD SHIPMENTS MADE= 14
 NUMBER OF LOCAL DELIVERIES MADE TO CONSOL CENTER= 153
 NUMBER OF DIRECT DISPATCHES UNDER CONSOLIDATION = 213
 TOTAL COST UNDER CONSOLIDATION SCHEME = 177640.75
 LINE-HAUL COST UNDER CONSOLIDATION SCHEME = 28321.25
 DIRECT DISPATCH COST UNDER CONSOL SCHEME = 90660.37
 TOTAL LOCAL DELIVERIES COST= 58659.17
 LTL SHIPMENT COST NO CONSOLIDATION= 184757.94
 TOTAL LOAD RECEIVED YEAR TO DATE: 1006227.94 POUNDS

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT CONSOLIDATION MODEL BY PRABIR BAGCHI
 DATE 10/29/1985 RUN NUMBER 1 OF 1

CURRENT TIME 0.1250E+03
 STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
CONSOLIDTD LOAD	0.1642E+05	0.1726E+05	0.1051E+01	0.0000E+00	0.4625E+05	18
LOADS PER DAY	0.3254E+01	0.1774E+01	0.5451E+00	0.1000E+01	0.8000E+01	114
LTL TRNST TIME	0.5781E+01	0.1299E+01	0.2246E+00	0.1432E+01	0.1037E+02	371
AVG TIME IN CC	0.4205E+01	0.1872E+01	0.4453E+00	0.1000E+01	0.7000E+01	156
AVG TIME IN SYS	0.8203E+01	0.8336E+00	0.1016E+00	0.7193E+01	0.9359E+01	7
TLOAD CENTER 1	0.0000E+00	0.0000E+00	0.9999E+04	0.0000E+00	0.0000E+00	18
TLOAD CENTER 2	0.0000E+00	0.0000E+00	0.9999E+04	0.0000E+00	0.0000E+00	18

FILE STATISTICS

FILE NUMBER	ASSOC NODE LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME

1
2
3

CALENDAR

80.9997
0.0000
8.5120

43.9074
0.0000
2.5349

156
0
13

156
0
13

64.9036
0.0000
5.7513

HISTOGRAM NUMBER 1

CONSOLIDTD LOAD

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER CELL LIMIT	0	20	40	60	80	100
7	0.389	0.389	0.0000E+00	+	+	+	+	+	+
1	0.056	0.444	0.5000E+04	+	+	+	+	+	+
0	0.000	0.444	0.1000E+05	+	+	+	+	+	+
0	0.000	0.444	0.1500E+05	+	+	+	+	+	+
2	0.111	0.556	0.2000E+05	+	+	+	+	+	+
1	0.056	0.611	0.2500E+05	+	+	+	+	+	+
4	0.222	0.833	0.3000E+05	+	+	+	+	+	+
0	0.000	0.833	0.3500E+05	+	+	+	+	+	+
0	0.000	0.833	0.4000E+05	+	+	+	+	+	+
2	0.111	0.944	0.4500E+05	+	+	+	+	+	+
1	0.056	1.000	0.5000E+05	+	+	+	+	+	+
0	0.000	1.000	0.5500E+05	+	+	+	+	+	+
0	0.000	1.000	0.6000E+05	+	+	+	+	+	+
0	0.000	1.000	0.6500E+05	+	+	+	+	+	+
0	0.000	1.000	0.7000E+05	+	+	+	+	+	+
0	0.000	1.000	0.7500E+05	+	+	+	+	+	+
0	0.000	1.000	0.8000E+05	+	+	+	+	+	+
0	0.000	1.000	0.8500E+05	+	+	+	+	+	+
0	0.000	1.000	0.9000E+05	+	+	+	+	+	+
0	0.000	1.000	0.9500E+05	+	+	+	+	+	+
0	0.000	1.000	0.1000E+06	+	+	+	+	+	+
0	0.000	1.000	INF	+	+	+	+	+	+
---				0	+	+	+	+	+
18				0	+	+	+	+	+

STATISTICS FOR VARIABLES BASED ON OBSERVATION

MEAN
VALUE

STANDARD
DEVIATION

COEFF. OF
VARIATION

MINIMUM
VALUE

MAXIMUM
VALUE

NUMBER OF
OBSERVATIONS

CONSOLIDTD LOAD

0.1642E+05

0.1726E+05

0.1051E+01

0.0000E+00

0.4625E+05

18

HISTOGRAM NUMBER 2

LOADS PER DAY

UPPER

CUML

RELA

OBSV

FREQ	FREQ	FREQ	CELL LIMIT	0	20	40	60	80	100
0	0.000	0.000	0.0000E+00	+	+	+	+	+	+
23	0.202	0.202	0.1000E+01	+	+	+	+	+	+
22	0.193	0.395	0.2000E+01	+	+	+	+	+	+
22	0.193	0.588	0.3000E+01	+	+	+	+	+	+
16	0.140	0.728	0.4000E+01	+	+	+	+	+	+
18	0.158	0.886	0.5000E+01	+	+	+	+	+	+
8	0.070	0.956	0.6000E+01	+	+	+	+	+	+
4	0.035	0.991	0.7000E+01	+	+	+	+	+	+
1	0.009	1.000	0.8000E+01	+	+	+	+	+	+
0	0.000	1.000	0.9000E+01	+	+	+	+	+	+
0	0.000	1.000	0.1000E+02	+	+	+	+	+	+
0	0.000	1.000	0.1100E+02	+	+	+	+	+	+
0	0.000	1.000	0.1200E+02	+	+	+	+	+	+
0	0.000	1.000	0.1300E+02	+	+	+	+	+	+
0	0.000	1.000	0.1400E+02	+	+	+	+	+	+
0	0.000	1.000	0.1500E+02	+	+	+	+	+	+
0	0.000	1.000	0.1600E+02	+	+	+	+	+	+
0	0.000	1.000	0.1700E+02	+	+	+	+	+	+
0	0.000	1.000	0.1800E+02	+	+	+	+	+	+
0	0.000	1.000	0.1900E+02	+	+	+	+	+	+
0	0.000	1.000	0.2000E+02	+	+	+	+	+	+
0	0.000	1.000	INF	+	+	+	+	+	+
---				0	20	40	60	80	100
114									

STATISTICS FOR VARIABLES BASED ON OBSERVATION

LOADS PER DAY	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
	0.3254E+01	0.1774E+01	0.5451E+00	0.1000E+01	0.8000E+01	114
HISTOGRAM NUMBER 3						

LTL TRNST TIME

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER CELL LIMIT	0	20	40	60	80	100
0	0.000	0.000	0.0000E+00	+	+	+	+	+	+
0	0.000	0.000	0.1000E+01	+	+	+	+	+	+
1	0.003	0.003	0.2000E+01	+	+	+	+	+	+
4	0.011	0.013	0.3000E+01	+	+	+	+	+	+
31	0.084	0.097	0.4000E+01	+	+	+	+	+	+
60	0.162	0.259	0.5000E+01	+	+	+	+	+	+
117	0.315	0.574	0.6000E+01	+	+	+	+	+	+
93	0.251	0.825	0.7000E+01	+	+	+	+	+	+

52	0.140	0.965	0.8000E+01	*****	C +
11	0.030	0.995	0.9000E+01	++	C
1	0.003	0.997	0.1000E+02	+	C
1	0.003	1.000	INF	+	C
---				0	+
371					100

***STATISTICS FOR VARIABLES BASED ON OBSERVATION**

LTL TRNST TIME	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
0.5781E+01	0.1299E+01	0.2246E+00	0.1432E+01	0.1037E+02	371	
HISTOGRAM NUMBER 4						
AVG TIME IN CC						

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER CELL LIMIT	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
0	0.000	0.000	0.0000E+00	+	+	100
14	0.090	0.090	0.1000E+01	+	+	+
21	0.135	0.224	0.2000E+01	+	+	+
23	0.147	0.372	0.3000E+01	+	+	+
27	0.173	0.545	0.4000E+01	+	+	+
24	0.154	0.699	0.5000E+01	+	+	+
26	0.167	0.865	0.6000E+01	+	+	+
21	0.135	1.000	0.7000E+01	+	+	+
0	0.000	1.000	0.8000E+01	+	+	+
0	0.000	1.000	0.9000E+01	+	+	+
0	0.000	1.000	0.1000E+02	+	+	+
0	0.000	1.000	INF	+	+	+
---				0	+	+
156					+	+

***STATISTICS FOR VARIABLES BASED ON OBSERVATION**

AVG TIME IN CC	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
0.4205E+01	0.1872E+01	0.4453E+00	0.1000E+01	0.7000E+01	156	
HISTOGRAM NUMBER 5						
AVG TIME IN SYS						

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER CELL LIMIT	0	+	20	+	40	+	60	+	80	+	100
0	0.000	0.000	0.0000E+00	+	+	+	+	+	+	+	+	+	+	+
0	0.000	0.000	0.1000E+01	+	+	+	+	+	+	+	+	+	+	+
0	0.000	0.000	0.2000E+01	+	+	+	+	+	+	+	+	+	+	+
0	0.000	0.000	0.3000E+01	+	+	+	+	+	+	+	+	+	+	+
0	0.000	0.000	0.4000E+01	+	+	+	+	+	+	+	+	+	+	+
0	0.000	0.000	0.5000E+01	+	+	+	+	+	+	+	+	+	+	+
0	0.000	0.000	0.6000E+01	+	+	+	+	+	+	+	+	+	+	+
0	0.000	0.000	0.7000E+01	+	+	+	+	+	+	+	+	+	+	+
3	0.429	0.429	0.8000E+01	+	+	+	+	+	+	+	+	+	+	+
3	0.429	0.857	0.9000E+01	+	+	+	+	+	+	+	+	+	+	+
1	0.143	1.000	0.1000E+02	+	+	+	+	+	+	+	+	+	+	+
0	0.000	1.000	INF	+	+	+	+	+	+	+	+	+	+	+
---				0		20		40		60		80		100
7														

STATISTICS FOR VARIABLES BASED ON OBSERVATION

MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
AVG TIME IN SYS 0.8203E+01	0.8336E+00	0.1016E+00	0.7193E+01	0.9359E+01	7

 * SUMMARY FOR A PERIOD OF: 250. DAYS *

CONSOLIDATION CENTER ZIP CODE: 606.
 DESTINATION ZIP CODE: 230.
 HOLDING TIME AT CONSOLIDATION CENTER = 7. DAYS
 MAXIMUM DISTANCE OF ORIGIN FROM CONSOL CENTER: 100. MILES
 LOAD FACTOR: 1.000
 ORDER NUMBER FACTOR: 1.00
 NUMBER OF LOADS ORIGINATING IN THE REGION = 734
 NUMBER OF CONSOLIDATED SHIPMENTS LTL MADE= 26
 NUMBER OF TRUCK-LOAD SHIPMENTS MADE= 27
 NUMBER OF LOCAL DELIVERIES MADE TO CONSOL CENTER= 298
 NUMBER OF DIRECT DISPATCHES UNDER CONSOLIDATION = 436
 TOTAL COST UNDER CONSOLIDATION SCHEME = 367456.31
 LINE-HAUL COST UNDER CONSOLIDATION SCHEME = 59546.51
 DIRECT DISPATCH COST UNDER CONSOL SCHEME = 190841.62
 TOTAL LOCAL DELIVERIES COST= 117068.19
 LTL SHIPMENT COST NO CONSOLIDATION= 377105.19
 TOTAL LOAD RECEIVED YEAR TO DATE: 2049586.00 POUNDS

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT CONSOLIDATION MODEL BY PRABIR BAGCHI

DATE 10/29/1985 RUN NUMBER 1 OF 1

CURRENT TIME 0.2500E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
CONSOLIDTD LOAD	0.1489E+05	0.1613E+05	0.1083E+01	0.0000E+00	0.4625E+05	36
LOADS PER DAY	0.3186E+01	0.1695E+01	0.5321E+00	0.1000E+01	0.8000E+01	231
LTL TRNST TIME	0.5836E+01	0.1253E+01	0.2147E+00	0.1432E+01	0.1037E+02	736
AVG TIME IN CC	0.4033E+01	0.1903E+01	0.4719E+00	0.1000E+01	0.7000E+01	299
AVG TIME IN SYS	0.7722E+01	0.1156E+01	0.1498E+00	0.5842E+01	0.9359E+01	16
TLOAD CENTER 1	0.0000E+00	0.0000E+00	0.9999E+04	0.0000E+00	0.0000E+00	36
TLOAD CENTER 2	0.0000E+00	0.0000E+00	0.9999E+04	0.0000E+00	0.0000E+00	36

FILE STATISTICS

FILE NUMBER	ASSOC NODE LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1		154.5274	85.5391	299	299	129.2035
2		0.0000	0.0000	0	0	0.0000
3	CALENDAR	12.9519	5.1309	22	22	8.8470

HISTOGRAM NUMBER 1

CONSOLIDTD LOAD

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER CELL LIMIT	0	20	40	60	80	100
16	0.444	0.444	0.0000E+00	+	+	+	+	+	+
1	0.028	0.472	0.5000E+04	++	+	+	+	+	+
0	0.000	0.472	0.1000E+05	+	+	+	+	+	+
0	0.000	0.472	0.1500E+05	+	+	+	+	+	+

C
C
C

100

80

60

40

20

0

16

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
AVG TIME IN SYS	0.7722E+01	0.1156E+01	0.1498E+00	0.5842E+01	0.9359E+01	16

APPENDIX F
MANOVA TEST RESULTS

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
HOLD	5	0 1 3 5 7
LFACTR	4	1 0.5 0.25 0.33
OFACTR	5	1 2 3 4 1.5
MAXD	3	1 2 1.5
LHD	2	8 13
NCNTR	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 688

MULTIVARIATE ANALYSIS OF VARIANCE AGGREGATE DATA SET
GENERAL LINEAR MODELS PROCEDURE

10:33 TUESDAY, JANUARY 14, 1986

2

DEPENDENT VARIABLE: DOLRAT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.	
MODEL	14	8268.45350539	590.60382181	77.67	0.0001	0.617698	11.6411	
ERROR	673	5117.47251425	7.60397105		ROOT MSE		DOLRAT MEAN	
CORRECTED TOTAL	687	13385.92601964			2.75752988		23.68793085	
SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
HOLD	4	1730.67681151	56.90	0.0001	4	1430.01507398	47.02	0.0001
LFACTR	3	3181.06862768	139.45	0.0001	2	1697.89033727	111.64	0.0001
OFACR	3	130.69871255	5.73	0.0008	3	32.08528710	1.41	0.2385
MAXD	2	246.63598774	16.22	0.0001	2	101.63932101	6.68	0.0013
LHD	1	2979.33681618	391.81	0.0001	1	2978.99911547	391.77	0.0001
NCNTR	1	0.03654973	0.00	0.9447	1	0.03654973	0.00	0.9447

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TSYS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.	
MODEL	14	498.07780264	35.57698590	46.40	0.0001	0.491137	12.3367	
ERROR	673	516.05500303	0.76679792		ROOT MSE		TSYS MEAN	
CORRECTED TOTAL	687	1014.13280567			0.87566999		7.09809593	
SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
HOLD	4	426.29081345	138.98	0.0001	4	430.03410813	140.20	0.0001
LFACTR	3	22.22937837	9.66	0.0001	2	1.94923482	1.27	0.2812
OFACTR	3	9.81747495	4.27	0.0055	3	16.82656170	7.31	0.0001
MAXD	2	15.97593572	10.42	0.0001	2	21.70224058	14.15	0.0001
LHD	1	16.40187251	21.39	0.0001	1	16.72317457	21.81	0.0001
NCNTR	1	7.36232764	9.60	0.0020	1	7.36232764	9.60	0.0020

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TSD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	14	380.59202100	27.18514436	51.22	0.0001	0.515834	45.6968
ERROR	673	357.22727144	0.53079832		ROOT MSE		TSD MEAN
CORRECTED TOTAL	687	737.81929244			0.72855907		1.59433140
SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE III SS	F VALUE	PR > F
HOLD	4	351.51680364	165.56	0.0001	326.33507945	153.70	0.0001
LFACTR	3	4.12070272	2.59	0.0512	1.25138084	1.18	0.3083
OFACTR	3	13.20804835	8.29	0.0001	14.63211284	9.19	0.0001
MAXD	2	10.00937737	9.43	0.0001	11.03884212	10.40	0.0001
LHD	1	0.68978247	1.30	0.2547	0.71486260	1.35	0.2463
NCNTR	1	1.04730645	1.97	0.1606	1.04730645	1.97	0.1606

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=673 MSE=7.60397

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=131.779

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	HOLD
	A	25.337	136	1
	A			
	A	25.268	200	0
	B	22.592	114	3
	B			
	B	21.986	122	7
	B			
	B	21.899	116	5

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: DOLRAT
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=7.60397
 CRITICAL VALUE OF STUDENTIZED RANGE=4.621
 MINIMUM SIGNIFICANT DIFFERENCE=1.11012
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=131.779
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	HOLD
	A	25.337	136	1
	A			
	A	25.268	200	0
	B	22.592	114	3
	B			
	B	21.986	122	7
	B			
	B	21.899	116	5

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=673 MSE=0.766798
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=131.779
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	HOLD
A	A	7.9833	200	0
A	A	7.7984	122	7
B	B	6.7366	116	5
C	C	6.2225	114	3
C	C	6.2104	136	1

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=0.766798
 CRITICAL VALUE OF STUDENTIZED RANGE=4.621
 MINIMUM SIGNIFICANT DIFFERENCE=0.352526
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=131.779
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	HOLD
	A	7.9833	200	0
	A			
	A	7.7984	122	7
	B	6.7366	116	5
	C	6.2225	114	3
	C			
	C	6.2104	136	1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=673 MSE=0.530798

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=131.779

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	HOLD
	A	2.4687	114	3
	A			
	A	2.3995	136	1
	B	1.7107	116	5
	C	1.2270	122	7
	D	0.7050	200	0

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=0.530798
 CRITICAL VALUE OF STUDENTIZED RANGE=4.621
 MINIMUM SIGNIFICANT DIFFERENCE=0.293302
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=131.779
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	HOLD
	A	2.4687	114	3
	A			
	A	2.3995	136	1
	B	1.7107	116	5
	C	1.2270	122	7
	D	0.7050	200	0

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARTISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=673 MSE=7.60397

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=163.361

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LFACTR
	A	25.725	120	0.25
	A			
	A	25.613	168	0.33
	B	24.056	172	0.5
	C	20.920	228	1

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: DOLRAT

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.

ALPHA=0.01 DF=673 MSE=7.60397

CRITICAL VALUE OF STUDENTIZED RANGE=4.419

MINIMUM SIGNIFICANT DIFFERENCE=0.953476

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=163.361

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	LFACTR
	A	25.725	120	0.25
	A			
	A	25.613	168	0.33
	B	24.056	172	0.5
	C	20.920	228	1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=673 MSE=0.766798
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=163.361
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LFACTR
	A	7.3744	120	0.25
	B	7.0615	172	0.5
	B	7.0586	228	1
	B	6.9917	168	0.33

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=0.766798
 CRITICAL VALUE OF STUDENTIZED RANGE=4.419
 MINIMUM SIGNIFICANT DIFFERENCE=0.302782
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=163.361
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	LFACTR
	A	7.3744	120	0.25
	B	7.0615	172	0.5
	B	7.0586	228	1
	B	6.9917	168	0.33

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.
ALPHA=0.01 DF=673 MSE=0.530798
WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=163.361
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LFACTR
	A	1.8274	120	0.25
	A			
	A	1.6228	172	0.5
B	A			
B	A			
B	A	1.6196	168	0.33
B				
B		1.4315	228	1

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=0.530798
 CRITICAL VALUE OF STUDENTIZED RANGE=4.419
 MINIMUM SIGNIFICANT DIFFERENCE=0.251915
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=163.361
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	LFACTR
	A	1.8274	120	0.25
B	A			
B	A	1.6228	172	0.5
B	A			
B	A	1.6196	168	0.33
B				
B		1.4315	228	1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=673 MSE=7.60397
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=88.5098
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	OFACTR
	A	25.725	120	4
	B	24.556	160	3
	B	23.977	180	2
	C	22.665	32	1.5
	C	21.634	196	1

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: DOLRAT
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=7.60397
 CRITICAL VALUE OF STUDENTIZED RANGE=4.621
 MINIMUM SIGNIFICANT DIFFERENCE=1.35456
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=88.5098
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	OFACTR
	A	25.725	120	4
B	A			
B	A	24.556	160	3
B	C	23.977	180	2
D	C	22.665	32	1.5
D				
D		21.634	196	1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=673 MSE=0.766798
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=88.5098
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	OFACTR
	A	7.3744	120	4
B	A			
B	A	7.1495	196	1
B	A			
B	A	7.0169	180	2
B	C			
B	C	6.9853	160	3
	C			
	C	6.7672	32	1.5

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=0.766798
 CRITICAL VALUE OF STUDENTIZED RANGE=4.621
 MINIMUM SIGNIFICANT DIFFERENCE=0.430149
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=88.5098
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	OFACTR
	A	7.3744	120	4
B	A			
B	A	7.1495	196	1
B	A			
B	A	7.0169	180	2
B	A			
B	A	6.9853	160	3
B	A			
B		6.7672	32	1.5

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=673 MSE=0.530798
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=88.5098
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	OFACTR
	A	1.8274	120	4
	A			
	A	1.6726	160	3
	A			
	A	1.5690	196	1
	A			
	A	1.5607	180	2
	A			
	B	0.6734	32	1.5

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=0.530798
 CRITICAL VALUE OF STUDENTIZED RANGE=4.621
 MINIMUM SIGNIFICANT DIFFERENCE=0.357885
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=88.5098
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	OFACTR
	A	1.8274	120	4
	A			
	A	1.6726	160	3
	A			
	A	1.5690	196	1
	A			
	A	1.5607	180	2
	A			
	B	0.6734	32	1.5

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=673 MSE=7.60397
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=222.042
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	MAXD
	A	24.094	290	1
	A			
	A	23.710	206	1.5
B				
B		23.052	192	2
B				

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: DOLRAT
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=7.60397
 CRITICAL VALUE OF STUDENTIZED RANGE=4.134
 MINIMUM SIGNIFICANT DIFFERENCE=0.76508
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=222.042
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	MAXD
	A	24.094	290	1
	A			
	A	23.710	206	1.5
B				
B				
B		23.052	192	2

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=673 MSE=0.766798
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=222.042
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	MAXD
A	A	7.2080	206	1.5
A	A	7.1969	192	2
B	B	6.9546	290	1

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=0.766798
 CRITICAL VALUE OF STUDENTIZED RANGE=4.134
 MINIMUM SIGNIFICANT DIFFERENCE=0.242956
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=222.042
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	MAXD
	A	7.2080	206	1.5
	A			
	A			
B		7.1969	192	2
B				
B		6.9546	290	1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=673 MSE=0.530798
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=222.042
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	MAXD
	A	1.7921	192	2
	A			
	A	1.6869	206	1.5
	B	1.3977	290	1

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=0.530798
 CRITICAL VALUE OF STUDENTIZED RANGE=4.134
 MINIMUM SIGNIFICANT DIFFERENCE=0.20214
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=222.042
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	MAXD
	A	1.7921	192	2
	A			
	A	1.6869	206	1.5
	B	1.3977	290	1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.
ALPHA=0.01 DF=673 MSE=7.60397
WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=311.951
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LHD
	A	25.179	449	13
	B	20.887	239	8

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: DOLRAT
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=7.60397
 CRITICAL VALUE OF STUDENTIZED RANGE=3.653
 MINIMUM SIGNIFICANT DIFFERENCE=0.570349
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=311.951
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	LHD
	A	25.179	449	13
	B	20.887	239	8

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.
ALPHA=0.01 DF=673 MSE=0.766798
WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=311.951
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LHD
	A	7.2301	449	13
	B	6.8500	239	8

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSYS
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
ALPHA=0.01 DF=673 MSE=0.766798
CRITICAL VALUE OF STUDENTIZED RANGE=3.653
MINIMUM SIGNIFICANT DIFFERENCE=0.181118
WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=311.951
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	LHD
	A	7.2301	449	13
	B	6.8500	239	8

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.
ALPHA=0.01 DF=673 MSE=0.530798
WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=311.951
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LHD
	A	1.7153	239	8
	B	1.5300	449	13

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=0.530798
 CRITICAL VALUE OF STUDENTIZED RANGE=3.653
 MINIMUM SIGNIFICANT DIFFERENCE=0.15069
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=311.951
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	LHD
	A	1.7153	239	8
	B	1.5300	449	13

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.
ALPHA=0.01 DF=673 MSE=7.60397
WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=343.895
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	NCNTR
	A	23.956	338	1
	A			
	A	23.429	350	2

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: DOLRAT
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=7.60397
 CRITICAL VALUE OF STUDENTIZED RANGE=3.653
 MINIMUM SIGNIFICANT DIFFERENCE=0.543214
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=343.895
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	NCNTR
	A	23.956	338	1
	A			
	A	23.429	350	2

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=673 MSE=0.766798
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=343.895
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	NCNTR
	A	7.1739	350	2
	A			
	A	7.0196	338	1

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=0.766798
 CRITICAL VALUE OF STUDENTIZED RANGE=3.653
 MINIMUM SIGNIFICANT DIFFERENCE=0.172501
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=343.895
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	NCNTR
	A	7.1739	350	2
	A			
	A	7.0196	338	1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: ISD
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=673 MSE=0.530798

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=343.895

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	NCNTR
	A	1.6301	338	1
	A	1.5598	350	2
	A			

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
 BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ.
 ALPHA=0.01 DF=673 MSE=0.530798
 CRITICAL VALUE OF STUDENTIZED RANGE=3.653
 MINIMUM SIGNIFICANT DIFFERENCE=0.143521
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=343.895
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY	GROUPING	MEAN	N	NCNTR
	A	1.6301	338	1
	A			
	A	1.5598	350	2

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: HOLD E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR	V'EV=1	
		DOLRAT	TSYS	TSD
8.93449732	96.15	0.00069115	-0.07115216	0.08475504
0.34873735	3.75	0.01549690	-0.01356405	-0.01216277
0.00901098	0.10	0.00052807	0.02324604	0.02679719

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL HOLD EFFECT

H = TYPE III SS&CP MATRIX FOR: HOLD
 E = ERROR SS&CP MATRIX
 P = DEP. VARIABLES = 3
 Q = HYPOTHESIS DF = 4
 NE = DF OF E = 673
 S = MIN(P,Q) = 3
 M = .5(ABS(P-Q)-1) = 0.0
 N = .5(NE-P-1) = 334.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 9.29224566 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = $2(S^*N+1)*TR(E^{-1}H)/(S^*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S^*N+1)$ DF
 $F(12,2009) = 518.56$ PROB > F = 0.0001

PILLAI'S TRACE $V = TR(H*INV(H+E))$ = 1.16683696 (SEE PILLAI'S TABLE #2)

F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 $F(12,2019) = 107.09$ PROB > F = 0.0001

WILKS' CRITERION $L = DET(E)/DET(H+E)$ = 0.07396578 (SEE RAO 1973 P 555)

$W = -(NE-.5(P-Q+1))*LN(L)$ = 1752.5948
 $U = NE-.5(P-Q+1)$ = 673.0000
 $Z = Sqrt((P*P*Q-Q-4)/(P*P+Q*Q-5))$ = 2.6458
 $B = (P*Q-2)/4$ = 2.5000

F APPROXIMATION = $(U*Z-2B)/((P*Q)*(1-L**1/Z)/L**1/Z)$ WITH P*Q AND U*Z-2B DF

$F(12,1775) = 247.97$ PROB > F = 0.0001

ROY'S MAXIMUM ROOT CRITERION = 8.93449732 (SEE AMS VOL 31 P 625)

FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND

$F(4,673) = 1503.23$ (UPPER BOUND)

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GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: LFACTR E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR	V'EV=1	DOLRAT	TSYS	TSD
0.42064707	99.12	0.01548465	-0.02097881	-0.00224905		
0.00372648	0.88	0.00019404	0.01838290	0.03313031		
0.00000000	0.00	-0.00104813	-0.07077393	0.08334725		

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL LFACTR EFFECT

H = TYPE III SS&CP MATRIX FOR: LFACTR
 E = ERROR SS&CP MATRIX
 P = DEP. VARIABLES = 3
 Q = HYPOTHESIS DF = 2
 NE= DF OF E = 673
 S = MIN(P,Q) = 2
 M = .5(ABS(P-Q)-1) = 0.0
 N = .5(NE-P-1) = 334.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 0.42437356 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = $2(S^*N+1) \cdot TR(E^{-1}H) / (S^*S(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S^*N+1)$ DF
 $F(6,1340) = 47.39$ PROB > F = 0.0001

PILLAI'S TRACE $V = TR(H \cdot INV(H+E)) = 0.29980805$ (SEE PILLAI'S TABLE #2)

F APPROXIMATION = $(2N+S+1) / (2M+S+1) \cdot V / (S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 $F(6,1344) = 39.50$ PROB > F = 0.0001

WILKS' CRITERION $L = DET(E) / DET(H+E) = 0.70129124$ (SEE RAO 1973 P 555)

EXACT F = $(1 - \sqrt{L}) / \sqrt{L} \cdot (NE+Q-P-1) / P$ WITH 2P AND $2(NE+Q-P-1)$ DF
 $F(6,1342) = 43.42$ PROB > F = 0.0001

ROY'S MAXIMUM ROOT CRITERION = 0.42064707 (SEE AMS VOL 31 P 625)

FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND

$F(2,673) = 141.55$ (UPPER BOUND)

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: MAXD E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR	V'EV=1	
		DOLRAT	TSYS	TSD
0.10297182	98.26	-0.01200982	0.03714294	0.01020714
0.00182506	1.74	0.00959024	0.00579458	0.02033484
0.00000000	0.00	-0.00216840	-0.06613483	0.08678565

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL MAXD EFFECT

H = TYPE III SS&CP MATRIX FOR: MAXD
 E = ERROR SS&CP MATRIX
 P = DEP. VARIABLES = 3
 Q = HYPOTHESIS DF = 2
 NE = DF OF E = 673
 S = MIN(P,Q) = 2
 M = .5(ABS(P-Q)-1) = 0.0
 N = .5(NE-P-1) = 334.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 0.10479688 (SEE PILLAI'S TABLE #3)
 F APPROXIMATION = $2(S*N+1)*TR(E^{-1}H)/(S*S*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S*N+1)$ DF
 F(6,1340) = 11.70 PROB > F = 0.0001

PILLAI'S TRACE $V = TR(H*INV(H+E))$ = 0.09518026 (SEE PILLAI'S TABLE #2)
 F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 F(6,1344) = 11.19 PROB > F = 0.0001

WILKS' CRITERION $L = DET(E)/DET(H+E)$ = 0.90498981 (SEE RAO 1973 P 555)
 EXACT F = $(1-SQRT(L))/SQRT(L)*(NE+Q-P-1)/P$ WITH 2P AND $2(NE+Q-P-1)$ DF
 F(6,1342) = 11.45 PROB > F = 0.0001

ROY'S MAXIMUM ROOT CRITERION = 0.10297182 (SEE AMS VOL 31 P 625)
 FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND
 F(2,673) = 34.65 (UPPER BOUND)

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: LHD E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR	V'EV=1	
		DOLRAT	TSYS	TSD
0.66295984	100.00	0.01478780	0.00705683	-0.02573165
0.00000000	0.00	-0.00356968	0.04764366	0.00000000
0.00000000	0.00	0.00308039	-0.05888357	0.08594953

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL LHD EFFECT

H = TYPE III SS&CP MATRIX FOR: LHD
 E = ERROR SS&CP MATRIX
 Q = DEP. VARIABLES = 3
 P = HYPOTHESIS DF = 1
 NE= DF OF E = 673
 S = MIN(P,Q) = 1
 M = .5(ABS(P-Q)-1) = 0.5
 N = .5(NE-P-1) = 334.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 0.66295984 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = $2(S^*N+1)*TR(E^{-1}H)/(S^*S*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S^*N+1)$ DF
 $F(3,671) = 148.28$ $PROB > F = 0.0001$

PILLAI'S TRACE $V = TR(H*INV(H+E)) = 0.39866257$ (SEE PILLAI'S TABLE #2)

F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 $F(3,671) = 148.28$ $PROB > F = 0.0001$

WILKS' CRITERION $L = DET(E)/DET(H+E) = 0.60133743$ (SEE RAO 1973 P 555)

EXACT $F = (1-L)/L*(NE+Q-P)/P$ WITH P AND NE+Q-P DF
 $F(3,671) = 148.28$ $PROB > F = 0.0001$

ROY'S MAXIMUM ROOT CRITERION = 0.66295984 (SEE AMS VOL 31 P 625)

FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND

$F(1,673) = 446.17$ (UPPER BOUND)

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: NCNTR E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR	V'EV=1	
		DOLRAT	TSYS	TSD
0.02162781	100.00	-0.00505142	0.06996808	-0.04086357
0.00000000	0.00	0.01407300	-0.00127169	0.00074270
0.00000000	0.00	-0.00416466	-0.02983021	0.07986900

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL NCNTR EFFECT

H = TYPE III SS&CP MATRIX FOR: NCNTR
 E = ERROR SS&CP MATRIX
 P = DEP. VARIABLES = 3
 Q = HYPOTHESIS DF = 1
 NE = DF OF E = 673
 S = MIN(P,Q) = 1
 M = .5(ABS(P-Q)-1) = 0.5
 N = .5(NE-P-1) = 334.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 0.02162781 (SEE PILLAI'S TABLE #3)
 F APPROXIMATION = $2(S^*N+1)*TR(E^{-1}H)/(S*S*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S^*N+1)$ DF
 $F(3,671) = 4.84$ PROB > F = 0.0026

PILLAI'S TRACE $V = TR(H*INV(H+E)) = 0.02116995$ (SEE PILLAI'S TABLE #2)
 F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 $F(3,671) = 4.84$ PROB > F = 0.0026

WILKS' CRITERION $L = DET(E)/DET(H+E) = 0.97883005$ (SEE RAO 1973 P 555)
 EXACT F = $(1-L)/L*(NE+Q-P)/P$ WITH P AND NE+Q-P DF
 $F(3,671) = 4.84$ PROB > F = 0.0026

ROY'S MAXIMUM ROOT CRITERION = 0.02162781 (SEE AMS VOL 31 P 625)
 FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND
 $F(1,673) = 14.56$ (UPPER BOUND)

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
HOLD	5	0 1 3 5 7
LFACTR	4	1 0.5 0.25 0.33
MAXD	3	1 2 1.5
LHD	2	8 13
NCNTR	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 480

MULTIVARIATE ANALYSIS OF VARIANCE JIT DATA SUBSET
GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: DOLRAT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.	
MODEL	11	6844.07533913	622.18866719	222.46	0.0001	0.839455	7.1942	
ERROR	468	1308.92025309	2.79683815		ROOT MSE		DOLRAT MEAN	
CORRECTED TOTAL	479	8152.99559222			1.67237500		23.24622241	
SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
HOLD	4	1757.76562800	157.12	0.0001	4	1769.41676212	158.16	0.0001
LFACTR	3	2409.37146764	287.15	0.0001	3	2369.67904279	282.42	0.0001
MAXD	2	48.95865485	8.75	0.0002	2	50.01903851	8.94	0.0002
LHD	1	2612.36990282	934.04	0.0001	1	2617.01197659	935.70	0.0001
NCNTR	1	15.60968582	5.58	0.0186	1	15.60968582	5.58	0.0186

MULTIVARIATE ANALYSIS OF VARIANCE JIT DATA SUBSET
GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TSYS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	11	280.92930783	25.53902798	97.93	0.0001	0.697123	6.9879
ERROR	468	122.05441529	0.26080003		ROOT MSE		TSYS MEAN
CORRECTED TOTAL	479	402.98372312			0.51068585		7.30818750
SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE III SS	F VALUE	PR > F
HOLD	4	178.08045542	170.71	0.0001	176.88041264	169.56	0.0001
LFACTR	3	2.90558396	3.71	0.0117	2.11356360	2.70	0.0444
MAXD	2	1.49654621	2.87	0.0577	1.47573651	2.83	0.0601
LHD	1	97.74455862	374.79	0.0001	97.52231080	373.94	0.0001
NCNTR	1	0.70216363	2.69	0.1015	0.70216363	2.69	0.1015

MULTIVARIATE ANALYSIS OF VARIANCE JIT DATA SUBSET
GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TSD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	11	413.14612336	37.55873849	252.43	0.0001	0.855768	19.6469
ERROR	468	69.63230976	0.14878699				TSD MEAN
CORRECTED TOTAL	479	482.77843313			0.38572916		1.96331250
SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE III SS	F VALUE	PR > F
HOLD	4	377.82707792	634.85	0.0001	378.44321876	635.88	0.0001
LFACTR	3	4.09853562	9.18	0.0001	4.82092149	10.80	0.0001
MAXD	2	0.46395489	1.56	0.2114	0.45292612	1.52	0.2193
LHD	1	30.57665046	205.51	0.0001	30.51327383	205.08	0.0001
NCNTR	1	0.17990447	1.21	0.2721	0.17990447	1.21	0.2721

MULTIVARIATE ANALYSIS OF VARIANCE JIT DATA SUBSET
GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: MILRAT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	11	89.60978874	8.14634443	350.67	0.0001	0.891802	6.6610
ERROR	468	10.87189599	0.02323055		ROOT MSE		MILRAT MEAN
CORRECTED TOTAL	479	100.48168473			0.15241570		2.28817861
SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE III SS	F VALUE	PR > F
HOLD	4	16.80498683	180.85	0.0001	16.60552669	178.70	0.0001
LFACTR	3	22.40746921	321.52	0.0001	23.05251923	330.78	0.0001
MAXD	2	0.36380829	7.83	0.0005	0.34498922	7.43	0.0007
LHD	1	49.93721930	2149.64	0.0001	49.87461442	2146.94	0.0001
NCNTR	1	0.09630511	4.15	0.0423	0.09630511	4.15	0.0423

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=468 MSE=2.79684
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	HOLD
	A	26.968	96	1
	B	22.814	96	0
	B	22.814	96	3
	C	21.875	96	5
	C	21.760	96	7

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=468 MSE=0.2608
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	HOLD
	A	8.0347	96	7
	A			
	A	7.9865	96	0
	B	7.0729	96	1
	B			
	B	6.9764	96	5
	C	6.4705	96	3

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=468 MSE=0.148787
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	HOLD
	A	3.0477	96	1
	B	2.8507	96	3
	C	1.8672	96	5
	D	1.3448	96	7
	E	0.7061	96	0

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: MILRAT
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=468 MSE=.0232305
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	HOLD
	A	2.6539	96	1
	B	2.2476	96	3
	B	2.2337	96	0
	C	2.1589	96	5
	C	2.1468	96	7

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.
ALPHA=0.01 DF=468 MSE=2.79684
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LFACTR
	A	25.725	120	0.25
	B	24.551	120	0.33
	C	22.947	120	0.5
	D	19.762	120	1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=468 MSE=0.2608
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LFACTR
A		7.3937	120	1
A				
A		7.3744	120	0.25
A				
A		7.2548	120	0.5
A				
A		7.2098	120	0.33
A				

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=468 MSE=0.148787
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LFACTR
	A	2.0847	120	1
	A	1.9912	120	0.33
	A	1.9499	120	0.5
B				
B				
B		1.8274	120	0.25

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: MILRAT
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=468 MSE=.0232305
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LFACTR
A	A	2.4986	120	0.25
A	A	2.4484	120	0.33
B	B	2.2579	120	0.5
C	C	1.9478	120	1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=468 MSE=2.79684

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=159.983

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	MAXD
	A	23.617	162	1
	A			
	A	23.190	158	1.5
B				
B		22.926	160	2
B				

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=468 MSE=0.2608

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=159.983

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	MAXD
	A	7.3731	160	2
	A			
	A	7.3049	158	1.5
	A			
	A	7.2473	162	1
	A			

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE-I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=468 MSE=0.148787
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=159.983
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	MAXD
	A	1.9964	160	2
	A			
	A	1.9785	158	1.5
	A			
	A	1.9159	162	1
	A			

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: MILRAT

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=468 MSE=.0232305

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=159.983

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	MAXD
	A	2.3203	162	1
	A			
	A	2.2800	158	1.5
B				
B				
B		2.2637	160	2

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.
ALPHA=0.01 DF=468 MSE=2.79684
WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=239.996
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LHD
	A	25.586	241	13
	B	20.887	239	8

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=468 MSE=0.2608

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=239.996

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LHD
	A	7.7625	241	13
	B	6.8500	239	8

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=468 MSE=0.148787

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=239.996

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LHD
	A	2.2093	241	13
	B	1.7153	239	8

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: MILRAT
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=468 MSE=.0232305
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=239.996
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	LHD
	A	2.6109	239	8
	B	1.9681	241	13

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=468 MSE=2.79684

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=239.983

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	NCNTR
	A	23.399	242	1
	A			
	A	23.091	238	2

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=468 MSE=0.2608

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=239.983

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	NCNTR
	A	7.3539	238	2
	A	7.2632	242	1

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=468 MSE=0.148787
 WARNING: CELL SIZES ARE NOT EQUAL.
 HARMONIC MEAN OF CELL SIZES=239.983
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	NCNTR
	A	1.9760	238	2
	A	1.9508	242	1
	A			

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: MILRAT
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=468 MSE=.0232305

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=239.983

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	NCNTR
	A	2.3065	242	1
	B	2.2695	238	2

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: HOLD E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR			V'EV=1
		DOLRAT	TSYS	TSD	MILRAT
15.72622134	92.42	0.01022369	-0.09276390	0.14115602	-0.04847971
1.16110351	6.82	0.00323557	0.03562464	-0.01191072	0.24732313
0.12762747	0.75	-0.02647935	0.05758497	0.04826955	0.16813249
0.00160500	0.01	-0.05184784	-0.01580362	-0.01533474	0.56822869

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL HOLD EFFECT

H = TYPE III SS&CP MATRIX FOR: HOLD
 E = ERROR SS&CP MATRIX
 P = DEP. VARIABLES = 4
 Q = HYPOTHESIS DF = 4
 NE= DF OF E = 468
 S = MIN(P,Q) = 4
 M = .5(ABS(P-Q)-1) = -0.5
 N = .5(NE-P-1) = 231.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 17.01655733 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = $2(S^*N+1)*TR(E^{-1}H)/(S^*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S^*N+1)$ DF
 $F(16, 1854) = 492.95$ PROB > F = 0.0001

PILLAI'S TRACE $V = TR(H*INV(H+E)) = 1.59227180$ (SEE PILLAI'S TABLE #2)

F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 $F(16, 1872) = 77.37$ PROB > F = 0.0001

WILKS' CRITERION $L = DET(E)/DET(H+E) = 0.02449427$ (SEE RAO 1973 P 555)

$W = -(NE-.5(P-Q+1))*LN(L) = 1734.1053$
 $U = NE-.5(P-Q+1) = 467.5000$
 $Z = SQRT((P*P*Q*Q-4)/(P*P+Q*Q-5)) = 3.0551$
 $B = (P*Q-2)/4 = 3.5000$

F APPROXIMATION = $(U*Z-2B)/(P*Q)*(1-L^{**1/Z})/L^{**1/Z}$ WITH P*Q AND U*Z-2B DF
 $F(16, 1421) = 210.29$ PROB > F = 0.0001

ROY'S MAXIMUM ROOT CRITERION = 15.72622134 (SEE AMS VOL 31 P 625)

FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND

$F(4, 468) = 1839.97$ (UPPER BOUND)

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: LFACTR E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR V'EV=1			
		DOLRAT	TSYS	TSD	MILRAT
2.23430163	96.58	0.00583999	0.00077220	-0.02537572	0.24276936
0.07460457	3.22	0.01043423	-0.09905780	0.13829056	-0.06938757
0.00462400	0.20	-0.02724880	0.05671957	0.04991818	0.30399640
0.00000000	0.00	-0.05117491	-0.02024564	-0.01928628	0.50843483

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL LFACTOR EFFECT

H = TYPE III SS&CP MATRIX FOR: LFACTOR
 E = ERROR SS&CP MATRIX
 P = DEP. VARIABLES = 4
 Q = HYPOTHESIS DF = 3
 NE = DF OF E = 468
 S = MIN(P,Q) = 3
 M = .5(ABS(P-Q)-1) = 0.0
 N = .5(NE-P-1) = 231.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 2.31353020 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = $2(S*N+1)*TR(E^{-1}H)/(S*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S*N+1)$ DF
 $F(12, 1391) = 89.39$ $PROB > F = 0.0001$

PILLAI'S TRACE $V = TR(H*INV(H+E)) = 0.76484209$ (SEE PILLAI'S TABLE #2)

F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 $F(12, 1401) = 39.95$ $PROB > F = 0.0001$

WILKS' CRITERION $L = DET(E)/DET(H+E) = 0.28639620$ (SEE RAO 1973 P 555)

$W = -(NE-.5(P-Q+1))*LN(L) = 583.9270$
 $U = NE-.5(P-Q+1) = 467.0000$
 $Z = SQRT((P*P*Q*Q-4)/(P*P+Q*Q-5)) = 2.6458$
 $B = (P*Q-2)/4 = 2.5000$

F APPROXIMATION = $(U*Z-2B)/(P*Q)*(1-L**1/Z)/L**1/Z$ WITH $P*Q$ AND $U*Z-2B$ DF
 $F(12, 1230) = 61.95$ $PROB > F = 0.0001$

ROY'S MAXIMUM ROOT CRITERION = 2.23430163 (SEE AMS VOL 31 P 625)

FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND

$F(3, 468) = 348.55$ (UPPER BOUND)

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: MAXD E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR - $V^T EV = 1$		
		DOLRAT	TSYS	TSD
0.05715495	98.88	0.02611547	-0.04858490	-0.00945210
0.00064795	1.12	0.00303086	0.09468154	-0.04647780
0.00000000	0.00	0.00583416	-0.04565768	0.14247894
0.00000000	0.00	-0.05271722	0.00550725	-0.00906710
				MILRAT
				-0.01604122
				0.10277255
				0.00000099
				0.63549341

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL MAXD EFFECT

H = TYPE III SS&CP MATRIX FOR: MAXD
 E = ERROR SS&CP MATRIX
 P = DEP. VARIABLES = 4
 Q = HYPOTHESIS DF = 2
 NE = DF OF E = 468
 S = MIN(P,Q) = 2
 M = .5*(ABS(P-Q)-1) = 0.5
 N = .5*(NE-P-1) = 231.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 0.05780290 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = $2(S^*N+1)*TR(E^{-1}H)/(S^*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S^*N+1)$ DF
 $F(8,928) = 3.35$ PROB > F = 0.0009

PILLAI'S TRACE $V = TR(H*INV(H+E)) = 0.05471241$ (SEE PILLAI'S TABLE #2)

F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 $F(8,932) = 3.28$ PROB > F = 0.0011

WILKS' CRITERION $L = DET(E)/DET(H+E) = 0.94532260$ (SEE RAO 1973 P 555)

EXACT F = $(1-SQRT(L))/SQRT(L)*(NE+Q-P-1)/P$ WITH 2P AND $2(NE+Q-P-1)$ DF
 $F(8,930) = 3.31$ PROB > F = 0.0010

ROY'S MAXIMUM ROOT CRITERION = 0.05715495 (SEE AMS VOL 31 P 625)

FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND

$F(2,468) = 13.37$ (UPPER BOUND)

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: LHD E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR			V'EV=1		
		DOLRAT	TSYS	TSD	MILRAT		
52.81552073	100.00	-0.05593727	0.01415963	-0.01951947	0.62839778		
0.00000000	0.00	-0.00943013	0.09309081	-0.00151981	0.06067423		
0.00000000	0.00	0.01690165	0.00425400	-0.00315395	0.12591280		
0.00000000	0.00	-0.00088091	-0.06749481	0.14912653	0.01588158		

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL LHD EFFECT

H = TYPE III SS&CP MATRIX FOR: LHD
 E = ERROR SS&CP MATRIX
 P = DEP. VARIABLES = 4
 Q = HYPOTHESIS DF = 1
 NE = DF OF E = 468
 S = MIN(P,Q) = 1
 M = .5(ABS(P-Q)-1) = 1.0
 N = .5(NE-P-1) = 231.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 52.81552073 (SEE PILLAI'S TABLE #3)
 F APPROXIMATION = $2(S*N+1)*TR(E^{-1}H)/(S*S*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S*N+1)$ DF
 $F(4,465) = 6139.80$ PROB > F = 0.0001

PILLAI'S TRACE $V = TR(H*INV(H+E)) = 0.98141800$ (SEE PILLAI'S TABLE #2)
 F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 $F(4,465) = 6139.80$ PROB > F = 0.0001

WILKS' CRITERION $L = DET(E)/DET(H+E) = 0.01858200$ (SEE RAO 1973 P 555)
 EXACT $F = (1-L)/L*(NE+Q-P)/P$ WITH P AND NE+Q-P DF
 $F(4,465) = 6139.80$ PROB > F = 0.0001

ROY'S MAXIMUM ROOT CRITERION = 52.81552073 (SEE AMS VOL 31 P 625)
 FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND
 $F(1,468) = 24717.66$ (UPPER BOUND)

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: NCNTR E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR V'EV=1			
		DOLRAT	TSYS	TSD	MILRAT
0.02081606	100.00	0.02989970	-0.05919827	-0.00267760	-0.07925194
0.00000000	0.00	-0.04887828	0.01431174	-0.01600734	0.63904961
0.00000000	0.00	0.00146544	-0.06971034	0.14956131	-0.00247180
0.00000000	0.00	0.01480274	0.06979432	0.00000000	0.00000000

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL NCNTR EFFECT

H = TYPE III SS&CP MATRIX FOR: NCNTR
 E = ERROR SS&CP MATRIX
 P = DEP. VARIABLES = 4
 Q = HYPOTHESIS DF = 1
 NE = DF OF E = 468
 S = MIN(P,Q) = 1
 M = .5(ABS(P-Q)-1) = 1.0
 N = .5(NE-P-1) = 231.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 0.02081606 (SEE PILLAI'S TABLE #3)
 F APPROXIMATION = $2(S*N+1)*TR(E^{-1}H)/(S*S*(2M+S+1))$ WITH $S(2N+S+1)$ AND $2(S*N+1)$ DF
 $F(4,465) = 2.42$ PROB > F = 0.0477

PILLAI'S TRACE $V = TR(H*INV(H+E))$ = 0.02039159 (SEE PILLAI'S TABLE #2)
 F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2N+S+1)$ AND $S(2N+S+1)$ DF
 $F(4,465) = 2.42$ PROB > F = 0.0477

WILKS' CRITERION $L = DET(E)/DET(H+E)$ = 0.97960841 (SEE RAO 1973 P 555)
 EXACT F = $(1-L)/L*(NE+Q-P)/P$ WITH P AND NE+Q-P DF
 $F(4,465) = 2.42$ PROB > F = 0.0477

ROY'S MAXIMUM ROOT CRITERION = 0.02081606 (SEE AMS VOL 31 P 625)
 FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND
 $F(1,468) = 9.74$ (UPPER BOUND)

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
HOLD	3	0 1 3
OFACTR	9	1 2 3 1.5 2.5 1.25 1.75 2.25 2.75

NUMBER OF OBSERVATIONS IN DATA SET = 54

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: DOLRAT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	10	161.59919664	16.15991966	100.20	0.0001	0.958851	1.6473
ERROR	43	6.93494087	0.16127769		ROOT MSE		DOLRAT MEAN
CORRECTED TOTAL	53	168.53413751			0.40159394		24.37844652
SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE III SS	F VALUE	PR > F
HOLD	2	159.81621102	495.47	0.0001	159.81621102	495.47	0.0001
OFACTR	8	1.78298561	1.38	0.2317	1.78298561	1.38	0.2317

MULTIVARIATE ANALYSIS OF VARIANCE JIT SUBSET 2
GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TSYS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	10	16.24227407	1.62422741	41.87	0.0001	0.906872	2.9170
ERROR	43	1.66794074	0.03878932		ROOT MSE		TSYS MEAN
CORRECTED TOTAL	53	17.91021481			0.19695004		6.75185185
SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE III SS	F VALUE	PR > F
HOLD	2	15.07595926	194.33	0.0001	15.07595926	194.33	0.0001
OFACTR	8	1.16631481	3.76	0.0020	1.16631481	3.76	0.0020

MULTIVARIATE ANALYSIS OF VARIANCE JIT SUBSET 2

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TSD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	10	98.07680741	9.80768074	334.10	0.0001	0.987293	7.1511
ERROR	43	1.26229630	0.02935573		ROOT MSE		TSD MEAN
CORRECTED TOTAL	53	99.33910370			0.17133513		2.39592593
SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE III SS	F VALUE	PR > F
HOLD	2	97.48347037	1660.38	0.0001	97.48347037	1660.38	0.0001
OFACTR	8	0.59333704	2.53	0.0239	0.59333704	2.53	0.0239

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=43 MSE=0.161278
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	HOLD
A		25.595	18	0
A				
A		25.595	18	1
B		21.946	18	3

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=43 MSE=.0387893
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	HOLD
	A	7.4161	18	0
	B	6.7161	18	1
	C	6.1233	18	3

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.
ALPHA=0.01 DF=43 MSE=.0293557
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	HOLD
	A	3.4461	18	1
	B	3.2422	18	3
	C	0.4994	18	0

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=43 MSE=0.161278
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	OFACTR
	A	24.718	6	1.5
	A			
	A	24.559	6	1.75
	A			
	A	24.476	6	2.25
	A			
	A	24.433	6	1
	A			
	A	24.401	6	1.25
	A			
	A	24.282	6	2.75
	A			
	A	24.221	6	2.5
	A			
	A	24.205	6	3
	A			
	A	24.110	6	2
	A			

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=43 MSE=.0387893
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	OFACTR
	A	6.9917	6	1.5
	A	6.9683	6	1.75
	A	6.7967	6	1
	A	6.7867	6	2.25
	A	6.7400	6	3
	A	6.7000	6	1.25
	A	6.6500	6	2.75
	A	6.6167	6	2
	A	6.5167	6	2.5
B				
B				
B				
B				
B				
B				
B				
B				
B				
B				
B				
B				
B				

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
 NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
 NOT THE EXPERIMENTWISE ERROR RATE.
 ALPHA=0.01 DF=43 MSE=.0293557
 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	OFACTR
	A	2.5733	6	2.5
	A	2.4967	6	2.25
B	A	2.4833	6	1.25
B	A	2.4333	6	1.75
B	A	2.3933	6	3
B	A	2.3717	6	1
B	A	2.2883	6	1.5
B	A	2.2633	6	2
B		2.2600	6	2.75

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: HOLD E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR	V'EV=1	DOLRAT	TSYS	TSD
100.35175244	85.93	-0.10042829	-0.29097117	0.84406936		
16.43283013	14.07	0.35502531	-0.01234488	0.26860023		
0.00000000	0.00	-0.13255933	0.75444381	0.17922203		

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL HOLD EFFECT

H = TYPE III SS&CP MATRIX FOR: HOLD
 E = ERROR SS&CP MATRIX
 P = DEP. VARIABLES = 3
 Q = HYPOTHESIS DF = 2
 NE = DF OF E = 43
 S = MIN(P,Q) = 2
 M = .5(ABS(P-Q)-1) = 0.0
 N = .5(NE-P-1) = 19.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 116.78458257 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = $2(S^*N+1)*TR(E^{-1}H)/(S^*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S^*N+1)$ DF
 $F(6,80) = 778.56$ PROB > F = 0.0001

PILLAI'S TRACE $V = TR(H*INV(H+E))$ = 1.93277034 (SEE PILLAI'S TABLE #2)

F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF
 $F(6,84) = 402.48$ PROB > F = 0.0001

WILKS' CRITERION $L = DET(E)/DET(H+E)$ = 0.00056598 (SEE RAO 1973 P 555)

EXACT F = $(1-SQRT(L))/SQRT(L)*(NE+Q-P-1)/P$ WITH 2P AND $2(NE+Q-P-1)$ DF
 $F(6,82) = 560.80$ PROB > F = 0.0001

ROY'S MAXIMUM ROOT CRITERION = 100.35175244 (SEE AMS VOL 31 P 625)

FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND

$F(2,43) = 2157.56$ (UPPER BOUND)

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: OFACTR E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR - $V'EV=1$	DOLRAT	TSYS	TSD
0.92369778	67.33	0.09064532	0.65437621	-0.49487313	
0.40241587	29.33	0.11833906	0.19343939	0.74029835	
0.04581818	3.34	0.36260182	-0.43402196	-0.15420328	

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL OFACTR EFFECT

H = TYPE-11 SS&CP MATRIX FOR: OFACTR

E = ERROR SS&CP MATRIX
P = DEP. VARIABLES = 3
Q = HYPOTHESIS DF = 8
NE = DF OF E = 43
S = MIN(P,Q) = 3
M = .5(ABS(P-Q)-1) = 2.0
N = .5(NE-P-1) = 19.5

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 1.37193183 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = $2(S^*N+1)*TR(E^{-1}H)/(S^*S*(2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S^*N+1)$ DF

$F(24, 119) = 2.27$ PROB > F = 0.0020

PILLAI'S TRACE $V = TR(H*INV(H+E)) = 0.81092342$ (SEE PILLAI'S TABLE #2)

F APPROXIMATION = $(2N+S+1)/(2M+S+1) * V/(S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF

$F(24, 129) = 1.99$ PROB > F = 0.0077

WILKS' CRITERION $L = DET(E)/DET(H+E) = 0.35442974$ (SEE RAO 1973 P 555)

$W = -(NE-.5(P-Q+1))*LN(L) = 46.6760$
 $U = NE-.5(P-Q+1) = 45.0000$
 $Z = SQRT((P*P*Q*Q-4)/(P*P*Q*Q-5)) = 2.9003$
 $B = (P*Q-2)/4 = 5.5000$

F APPROXIMATION = $(U*Z-2B)/(P*Q)*(1-L^{**1/Z})/L^{**1/Z}$ WITH P*Q AND U*Z-2B DF

$F(24, 119) = 2.14$ PROB > F = 0.0039

ROY'S MAXIMUM ROOT CRITERION =

0.92369778 (SEE AMS VOL 31 P 625)

FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND

$F(8, 43) = 4.96$ (UPPER BOUND)

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INPUT DATA: INCREASED VENDOR CONCENTRATIONS

OBS	DOLRAT	PCTHRU	TSYS	TSD	HOLD	LFACTR	OFACTR	NCNTR	PCDEST
1	23.7976	56.8002	5.39	1.29	1	1	9	2	38.0085
2	24.1257	0.0000	7.41	0.51	0	1	9	2	0.0000
3	23.3842	58.7862	5.45	1.28	1	1	9	2	40.5495
4	25.0555	0.0000	7.42	0.51	0	1	9	2	0.0000
5	23.4768	56.9672	5.56	1.40	1	1	10	2	39.1257
6	24.1375	0.0000	7.41	0.49	0	1	10	2	0.0000
7	23.0626	59.0489	5.47	1.33	1	1	10	2	41.6033
8	24.3143	0.0000	7.42	0.51	0	1	10	2	0.0000
9	25.1197	40.9229	5.54	1.22	1	1	9	1	27.1099
10	24.1234	0.0000	7.43	0.50	0	1	9	1	0.0000
11	25.4748	40.7307	5.66	1.22	1	1	9	1	27.2343
12	23.6611	0.0000	7.43	0.50	0	1	9	1	0.0000
13	25.2279	40.7787	6.10	1.43	1	1	8	1	26.8101
14	24.1840	0.0000	7.41	0.50	0	1	8	1	0.0000
15	25.5031	40.9647	5.85	1.45	1	1	8	1	26.8342
16	24.2708	0.0000	7.42	0.51	0	1	8	1	0.0000
17	25.2601	40.7494	6.01	1.32	1	1	7	1	26.3466
18	24.2211	0.0000	7.42	0.50	0	1	7	1	0.0000
19	25.3169	40.9938	5.94	1.35	1	1	7	1	26.7469
20	24.1342	0.0000	7.42	0.50	0	1	7	1	0.0000
21	25.2116	41.0478	5.78	1.37	1	1	6	1	25.8770
22	24.2214	0.0000	7.41	0.50	0	1	6	1	0.0000
23	25.4246	40.8782	5.59	1.38	1	1	6	1	25.8941
24	24.2259	0.0000	7.42	0.50	0	1	6	1	0.0000
25	25.4854	41.1475	5.70	1.40	1	1	5	1	25.9563
26	24.4930	0.0000	7.40	0.49	0	1	5	1	0.0000
27	25.3075	40.5435	5.60	1.40	1	1	5	1	25.7065
28	24.1416	0.0000	7.40	0.49	0	1	5	1	0.0000
29	25.0684	40.9016	5.60	1.20	1	1	10	1	27.5683
30	24.0803	0.0000	7.40	0.50	0	1	10	1	0.0000
31	25.3840	40.8424	5.70	1.29	1	1	10	1	14.2391
32	24.3407	0.0000	7.40	0.51	0	1	10	1	0.0000
33	25.8243	40.7104	5.50	1.38	1	1	2	1	18.7158
34	24.4383	0.0000	7.40	0.50	0	1	2	1	0.0000
35	25.6299	39.4022	5.50	1.37	1	1	2	1	18.3424
36	24.2773	0.0000	7.40	0.49	0	1	2	1	0.0000
37	25.3785	39.8907	5.70	1.30	1	1	3	1	22.1311
38	24.1987	0.0000	7.40	0.50	0	1	3	1	0.0000
39	25.1743	42.1196	5.72	1.30	1	1	3	1	24.5471
40	23.9668	0.0000	7.40	0.50	0	1	3	1	0.0000
41	25.5629	39.9590	5.96	1.30	1	1	4	1	24.3852
42	24.5018	0.0000	7.40	0.49	0	1	4	1	0.0000
43	25.3694	41.5082	5.68	1.41	1	1	4	1	25.3397
44	25.3694	0.0000	5.68	1.41	1	1	4	1	0.0000
45	24.4238	57.4863	5.37	1.28	1	1	5	2	34.4262
46	24.2285	0.0000	7.41	0.49	0	1	5	2	0.0000
47	23.6977	56.4130	5.48	1.31	1	1	5	2	34.1848

48	24.0051	0.0000	7.42	0.49	0	1	5	2	0.0000
49	24.2825	57.1494	5.34	1.51	1	1	6	2	35.4281
50	24.2730	0.0000	7.41	0.50	0	1	6	2	0.0000
51	23.2474	57.3370	5.43	1.43	1	1	6	2	37.5000
52	24.1123	0.0000	7.42	0.50	0	1	6	2	0.0000
53	20.6845	56.9331	5.53	1.22	1	1	7	2	38.7637
54	21.3299	0.0000	7.41	0.52	0	1	7	2	0.0000
55	23.6303	57.8416	5.48	1.26	1	1	7	2	37.9270
56	24.1066	0.0000	7.42	0.51	0	1	7	2	0.0000

INPUT DATA: INCREASED VENDOR CONCENTRATIONS

OBS	DOLRAT	PCTHRU	TSYS	TSD	HOLD	LFACTR	OFACTR	NCNTR	PCDEST
57	23.2363	56.9331	5.43	1.30	1	1	8	2	38.7637
58	24.1445	0.0000	7.42	0.50	0	1	8	2	0.0000
59	23.1607	58.2541	5.46	1.31	1	1	8	2	39.7758
60	24.2435	0.0000	7.43	0.50	0	1	8	2	0.0000
61	25.2801	55.7377	5.47	1.14	1	1	3	2	26.0474
62	24.1753	0.0000	7.41	0.51	0	1	3	2	0.0000
63	23.9606	58.5145	5.44	1.27	1	1	3	2	30.3442
64	24.2017	0.0000	7.42	0.51	0	1	3	2	0.0000
65	26.0523	56.0109	5.40	1.21	1	1	2	2	16.5301
66	24.0495	0.0000	7.41	0.51	0	1	2	2	0.0000
67	25.4620	56.6576	5.45	1.25	1	1	2	2	19.7011
68	24.2591	0.0000	7.42	0.50	0	1	2	2	0.0000
69	24.3163	56.2842	5.31	1.38	1	1	4	2	32.2404
70	24.3512	0.0000	7.41	0.49	0	1	4	2	0.0000
71	24.4745	57.5408	5.37	1.34	1	1	4	2	32.5408
72	24.1234	0.0000	7.42	0.50	0	1	4	2	0.0000
73	25.0210	41.0565	5.75	1.41	1	1	15	1	28.0874
74	24.0832	0.0000	7.42	0.50	0	1	15	1	0.0000
75	25.2893	40.0000	5.67	1.38	1	1	15	1	27.8080
76	24.1791	0.0000	7.42	0.50	0	1	15	1	0.0000

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
OFACTR	9	2 3 4 5 6 7 8 9 10
NCNTR	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 36

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: DOLRAT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	30.66905040	3.40767227	6.69	0.0001	0.698432	2.8986
ERROR	26	13.24224751	0.50931721		ROOT MSE		DOLRAT MEAN
CORRECTED TOTAL	35	43.91129791			0.71366464		24.62093833
SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE III SS	F VALUE	PR > F
OFACTR	8	10.27917292	2.52	0.0354	10.27917292	2.52	0.0354
NCNTR	1	20.38987748	40.03	0.0001	20.38987748	40.03	0.0001

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TSYS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	1.04030000	0.11558889	8.75	0.0001	0.751867	2.0585
ERROR	26	0.34332222	0.01320470		ROOT MSE		TSYS MEAN
CORRECTED TOTAL	35	1.38362222			0.11491171		5.58222222
SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE III SS	F VALUE	PR > F
OFACTR	8	0.26002222	2.46	0.0393	0.26002222	2.46	0.0393
NCNTR	1	0.78027778	59.09	0.0001	0.78027778	59.09	0.0001

MULTIVARIATE ANALYSIS OF VARIANCE JIT DATA SUBSET/HI VENDOR CONCENTRATION

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GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TSD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	0.11366667	0.01262963	2.87	0.0172	0.498053	5.0202
ERROR	26	0.11455556	0.00440598		ROOT MSE		TSD MEAN
CORRECTED TOTAL	35	0.22822222			0.06637758		1.32222222
SOURCE	DF	TYPE I SS	F VALUE	PR > F	TYPE III SS	F VALUE	PR > F
OFAC1R	8	0.10432222	2.96	0.0171	0.10432222	2.96	0.0171
NCNTR	1	0.00934444	2.12	0.1573	0.00934444	2.12	0.1573

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,

NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=26 MSE=0.509317

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	OFACTR
	A	25.742	4	2
B	A	24.948	4	3
B	A	24.931	4	4
B	A	24.729	4	5
B	A	24.542	4	6
B	A	24.444	4	9
B	A	24.282	4	8
B	A	24.248	4	10
B	A	23.723	4	7

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,

NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=26 MSE=.0132047

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	OFACTR
	A	5.7400	4	7
B	A			
B	A	5.7100	4	8
B	A			
B	A	5.5825	4	10
B	A			
B	A	5.5825	4	3
B	A			
B	A	5.5800	4	4
B	A			
B	A	5.5375	4	5
B	A			
B	A	5.5350	4	6
B	A			
B	A	5.5100	4	9
B	A			
B	A	5.4625	4	2
B	A			

MULTIVARIATE ANALYSIS OF VARIANCE JIT DATA SUBSET/HI VENDOR CONCENTRATION

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=26 MSE=0.004406

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	OFACTR
	A	1.4225	4	6
	A			
	A	1.3725	4	8
	A			
B	A	1.3575	4	4
B	A			
B	A	1.3475	4	5
B	A			
B	A	1.3050	4	10
B	A			
B	A	1.3025	4	2
B	A			
B	A	1.2875	4	7
B	A			
B		1.2525	4	9
B				
B		1.2525	4	3
B				

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: DOLRAT
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
-- NOT THE EXPERIMENTWISE ERROR RATE.
ALPHA=0.01 DF=26 MSE=0.509317
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	NCNTR
	A	25.374	18	1
	B	23.868	18	2

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSYS
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=26 MSE=.0132047
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	NCNTR
	A	5.7294	18	1
	B	5.4350	18	2

GENERAL LINEAR MODELS PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TSD

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE.

ALPHA=0.01 DF=26 MSE=0.004406

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	MCNTR
	A	1.3383	18	1
	A			
	A	1.3061	18	2

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: OFACTR E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR	V'EV=1	DOLRAT	TSYS	TSD
1.82126494	63.26	-0.22733064	1.38025451	-0.66494838		
0.90668207	31.49	-0.00946020	0.17196322	2.90958294		
0.15111982	5.25	0.17265194	1.09049439	-0.08330943		

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL OFACTR EFFECT

H = TYPE III SS&CP MATRIX FOR: OFACTR.

E = ERROR SS&CP MATRIX
 P = DEP. VARIABLES = 3
 Q = HYPOTHESIS DF = 8
 NE = DF OF E = 26
 S = MIN(P,Q) = 3
 M = .5(ABS(P-Q)-1) = 2.0
 N = .5(NE-P-1) = 11.0

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 2.87906684 (SEE PILLAI'S TABLE #3)F APPROXIMATION = $2(S^*N+1) * TR(E^{-1}H) / (S^*S * (2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S^*N+1)$ DF

F(24, 68) = 2.72 PROB > F = 0.0007

PILLAI'S TRACE $V = TR(H * INV(H+E))$ = 1.25235849 (SEE PILLAI'S TABLE #2)F APPROXIMATION = $(2N+S+1) / (2M+S+1) * V / (S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF

F(24, 78) = 2.33 PROB > F = 0.0028

WILKS' CRITERION $L = DET(E) / DET(H+E)$ = 0.16149434 (SEE RAO 1973 P 555)

$W = -(NE - .5(P-Q+1)) * LN(L)$ = 51.0520
 $U = NE - .5(P-Q+1)$ = 28.0000
 $Z = SQRT((P * P * Q * Q - 4) / (P * P + Q * Q - 5))$ = 2.9003
 $B = (P * Q - 2) / 4$ = 5.5000

F APPROXIMATION = $(U * Z - 2B) / (P * Q) * (1 - L^{**1/Z}) / L^{**1/Z}$ WITH $P * Q$ AND $U * Z - 2B$ DF

F(24, 70) = 2.56 PROB > F = 0.0012

ROY'S MAXIMUM ROOT CRITERION = 1.82126494 (SEE AMS VOL 31 P 625)

FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND

$F(8, 26) = 5.92$ (UPPER BOUND)

GENERAL LINEAR MODELS PROCEDURE

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE III SS&CP MATRIX FOR: NCNTR E = ERROR SS&CP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR	V'EV=1	DOLRAT	TSYS	TSD
3.17857276	100.00	0.14955311	1.19820808	0.50822855		
0.00000000	0.00	0.01130017	-0.37974071	2.94218855		
0.00000000	0.00	0.24307114	-1.24255634	0.00000000		

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL NCNTR EFFECT

H = TYPE III SS&CP MATRIX FOR: NCNTR

E = ERROR SS&CP MATRIX
P = DEP. VARIABLES = 3
Q = HYPOTHESIS DF = 1
NE = DF OF E = 26
S = MIN(P,Q) = 1
M = .5(ABS(P-Q)-1) = 0.5
N = .5(NE-P-1) = 11.0

HOTELLING-LAWLEY TRACE = $TR(E^{-1}H)$ = 3.17857276 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = $2(S^{*N+1}) * TR(E^{-1}H) / (S^{*S} * (2M+S+1))$ WITH $S(2M+S+1)$ AND $2(S^{*N+1})$ DF

F(3,24) = 25.43 PROB > F = 0.0001

PILLAI'S TRACE $V = TR(H * INV(H+E))$ = 0.76068384 (SEE PILLAI'S TABLE #2)

F APPROXIMATION = $(2M+S+1) / (2M+S+1) * V / (S-V)$ WITH $S(2M+S+1)$ AND $S(2N+S+1)$ DF

F(3,24) = 25.43 PROB > F = 0.0001

WILKS' CRITERION $L = DET(E) / DET(H+E)$ = 0.23931616 (SEE RAO 1973 P 555)

EXACT F = $(1-L) / L * (NE+Q-P) / P$ WITH P AND NE+Q-P DF

F(3,24) = 25.43 PROB > F = 0.0001

ROY'S MAXIMUM ROOT CRITERION = 3.17857276 (SEE AMS VOL 31 P 625)

FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND

F(1,26) = 82.64 (UPPER BOUND)

VITA

Prabir Kumar Bagchi was born at Bhatpara (near Calcutta), India on July 9, 1948. He attended elementary schools at Bhatpara and was graduated from Bhatpara High School in June 1964. He entered the Bengal Engineering College (University of Calcutta) the following July, and in June 1969 he received the Bachelor of Engineering degree in Mechanical Engineering. Immediately after graduation he started work as a Management Trainee with Philips India Limited. On completion of one year's training he started as a Manufacturing Engineer at the Philips plant at Calcutta, India. Thereafter he worked in various capacities in Project and Materials Management with Philips in various establishments in India. In 1978 he was appointed to the position of Manager of Planning and Material Control at the Philips plant at Calcutta.

After a long thirteen-year stay with Philips, he entered The Graduate School of The University of Tennessee, Knoxville, in September 1982. He received the Master of Science degree with a major in Management Science in March 1984. He received the Doctor of Philosophy degree with a major in Business Administration in June 1986.

The author is a member of the Council of Logistics Management, and The Institute of Management Sciences. Mr. Bagchi is now with the University of Toledo as Assistant Professor in the department of Information Systems and Operations Management.