AN INVESTIGATION OF FREIGHT CONSOLIDATION AND WAREHOUSE STRATEGIES IN INDUSTRIAL DISTRIBUTION SYSTEMS

DISSERTATION

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

By

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1982

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1982
ACKNOWLEDGEMENTS

A number of people and organizations have provided guidance and support in this research effort. The dissertation committee contributed considerable time to the project. Professor Bernard J. La Londe provided valuable guidance and advice as the chairman of the committee. Professor Glenn W. Milligan and James L. Ginter assisted in the development of the methodology and provided many useful comments for improving the study and manuscript. Professor Wesley J. Johnston assisted with supporting comments and advice. Professor John R. Grabner provided extensive assistance by answering numerous questions of theory and realism about the research. Due to the proximity of his office to mine, he was interrupted frequently for some query or other. The committee members have been most supportive throughout my doctoral study. I hope I can emulate the professional standards these professors exemplify with the same good-naturedness.

Previously developed computer programs provided great help in the development of the programs used in this research. Professor Basheer Khumawala gave permission for use of his warehouse location algorithm which with some modification was used to determine the warehouse and pooling point locations for the simulation runs. Major James M. Masters permitted me to use his freight consolidation simulation program and supporting programs. His consolidation program was modified to investigate multiple products from multiple plants. Major Masters' program logic also served as the basis for developing the programs to simulate
the other distribution alternatives. The completion of this research project was considerably shortened through the generosity of these two researchers.

This research was supported in part by a grant from A. T. Kearney, Inc., and the National Council of Physical Distribution Management. These organizations are commended for their continued support of doctoral research in physical distribution. The grant itself provided some indication that the research effort potentially had some value to the practice of physical distribution management. In addition to this support, anonymous corporations supplied transportation rates, warehousing costs, and shipment data. The researcher is greatly indebted to all these sources for the research surely would not have been possible without their contributions.

My appreciation is extended to the staffs of the Instruction and Research Computer Center and the College of Administrative Science Data Center for their assistance. Everyone from operators to consultants were most pleasant and helpful. They solved many programming and systems problems I could not have solved myself.

Finally, the entire doctoral experience could not have been successfully completed without the support of my family and friends who provided both physical and emotional assistance. My mother, Jean C. Rhoad, worked tirelessly to assist me professionally and to care for my daughter Holly. My father, Dr. Claude E. Rhoad, provided encouragement and confidence in the probability of my completing the task. My daughter Holly was understanding and flexible to my needs at least as much as I was to hers. To them I reaffirm my love.

My appreciation is extended to Marjorie King for her support and for typing this manuscript. Thanks also go to my officemates who
suffered through my trials and tribulations as a doctoral student, particularly Michael Czinkota and Nancy Offutt who endured my frustrations longest. Cindy Coykendale was also quite helpful. Without the support and understanding of these people, this effort would have certainly taken much longer if it ever had been completed at all.
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>ACKNOWLEDGEMENTS</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>VITA</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>ix</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
</tbody>
</table>

## CHAPTER

### I. OVERVIEW

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Statement of the Research Issue</td>
<td>3</td>
</tr>
<tr>
<td>Scope of the Research</td>
<td>5</td>
</tr>
<tr>
<td>Research Questions</td>
<td>7</td>
</tr>
<tr>
<td>Research Methodology</td>
<td>8</td>
</tr>
<tr>
<td>Limitations</td>
<td>11</td>
</tr>
<tr>
<td>Potential Contributions</td>
<td>13</td>
</tr>
</tbody>
</table>

### II. LITERATURE REVIEW

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose and Scope</td>
<td>16</td>
</tr>
<tr>
<td>Systems Theory and Physical Distribution</td>
<td>17</td>
</tr>
<tr>
<td>Means of Studying Physical Distribution Systems</td>
<td>18</td>
</tr>
<tr>
<td>Warehouse Location and Freight Consolidation</td>
<td>30</td>
</tr>
<tr>
<td>Comparison of Different Systems</td>
<td>31</td>
</tr>
<tr>
<td>Approaches to Facility Location</td>
<td>33</td>
</tr>
<tr>
<td>Summary of Approaches to Warehouse Location</td>
<td>38</td>
</tr>
<tr>
<td>Freight Consolidation Research</td>
<td>39</td>
</tr>
<tr>
<td>Summary</td>
<td>52</td>
</tr>
<tr>
<td>Implications for the Present Research</td>
<td>53</td>
</tr>
</tbody>
</table>

### III. RESEARCH METHODOLOGY

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overview</td>
<td>54</td>
</tr>
<tr>
<td>Research Questions and Hypotheses</td>
<td>54</td>
</tr>
<tr>
<td>Variables</td>
<td>59</td>
</tr>
<tr>
<td>Steps in the Research Project</td>
<td>62</td>
</tr>
<tr>
<td>Pilot Study</td>
<td>71</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (continued)

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV. FINDINGS AND RESULTS.</td>
<td>79</td>
</tr>
<tr>
<td>Hypothesis Tests</td>
<td>80</td>
</tr>
<tr>
<td>Discriminant and Regression Findings</td>
<td>91</td>
</tr>
<tr>
<td>Discriminant Analysis</td>
<td>91</td>
</tr>
<tr>
<td>Regression Analyses</td>
<td>100</td>
</tr>
<tr>
<td>Additional Findings</td>
<td>115</td>
</tr>
<tr>
<td>Analysis of Real Data</td>
<td>115</td>
</tr>
<tr>
<td>Cost Versus Service</td>
<td>117</td>
</tr>
<tr>
<td>V. CONCLUSIONS</td>
<td>129</td>
</tr>
<tr>
<td>Review of the Study</td>
<td>129</td>
</tr>
<tr>
<td>Hypothesis Test Results</td>
<td>133</td>
</tr>
<tr>
<td>Implications of the Research</td>
<td>137</td>
</tr>
<tr>
<td>Theoretical Considerations</td>
<td>137</td>
</tr>
<tr>
<td>Managerial Considerations</td>
<td>143</td>
</tr>
<tr>
<td>Summary</td>
<td>146</td>
</tr>
<tr>
<td>Suggestions for Future Research</td>
<td>147</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>150</td>
</tr>
</tbody>
</table>

APPENDICES

A. Khumawala Warehouse Location Model........... 156
B. Geoffrion and Graves Warehouse Location Model... 158
C. Kuehn and Hamburger Warehouse Location Model..... 161
D. House Warehouse Location Model................ 163
E. Simulation Model Formulation.................. 165
F. Assumptions of Simulation Model............... 167
G. Listing of Computer Programs.................. 174
H. MANOVA's and Duncan's Tests................... 205
I. Regression ANOVA Tables and Coefficients....... 304
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LOGISTICS ACTIVITIES - EXAMPLE 1</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>LOGISTICS ACTIVITIES - EXAMPLE 2</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>CLASSIFICATION OF MODELS AND MODEL VARIABLES - EXAMPLE 1</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>CLASSIFICATION OF MODELS AND MODEL VARIABLES - EXAMPLE 2</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>CLASSIFICATION OF MODELS AND MODEL VARIABLES - EXAMPLE 3</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>FACTORS AND LEVELS IN MASTERS' DESIGN</td>
<td>43</td>
</tr>
<tr>
<td>7</td>
<td>EXPLAINED VARIANCE OF MASTERS' EXPERIMENT</td>
<td>44</td>
</tr>
<tr>
<td>8</td>
<td>FACTORS AND LEVELS OF JACKSON'S DESIGN</td>
<td>46</td>
</tr>
<tr>
<td>9</td>
<td>EXPLAINED VARIANCE OF JACKSON'S EXPERIMENT</td>
<td>47</td>
</tr>
<tr>
<td>10</td>
<td>COSTS, DELIVERY TIME, MEANS AND VARIANCES FOR MASTERS' AND JACKSON'S STUDIES</td>
<td>49</td>
</tr>
<tr>
<td>11</td>
<td>EXPLAINED VARIANCE IN MASTERS' AND JACKSON'S STUDIES</td>
<td>50</td>
</tr>
<tr>
<td>12</td>
<td>PREDICTOR VARIABLES AND LEVELS</td>
<td>61</td>
</tr>
<tr>
<td>13</td>
<td>CELLS IN WHICH COST PER HUNDREDWEIGHT OF UNCONSOLIDATED SHIPMENTS FROM PLANTS WAS SIGNIFICANTLY GREATER THAN COST PER HUNDREDWEIGHT OF OTHER STRUCTURES</td>
<td>82</td>
</tr>
<tr>
<td>14</td>
<td>CELLS IN WHICH COST PER HUNDREDWEIGHT OF UNCONSOLIDATED SHIPMENTS FROM PLANTS WAS NOT MORE EXPENSIVE THAN THE ALTERNATIVE SYSTEM COST PER HUNDREDWEIGHT</td>
<td>84</td>
</tr>
<tr>
<td>15</td>
<td>CELLS IN WHICH MEAN DELIVERY TIME FOR A CONSOLIDATION STRUCTURE WAS NOT SIGNIFICANTLY GREATER THAN ASSOCIATED UNCONSOLIDATED STRUCTURE</td>
<td>87</td>
</tr>
<tr>
<td>16</td>
<td>CELLS IN WHICH DELIVERY TIME VARIANCE FOR CONSOLIDATION FROM PLANTS WAS SIGNIFICANTLY GREATER THAN DELIVERY TIME VARIANCE FOR OTHER STRUCTURES</td>
<td>90</td>
</tr>
<tr>
<td>17</td>
<td>LOWEST COST STRUCTURES SUBJECT TO MEAN DELIVERY TIME OF LESS THAN 6 DAYS</td>
<td>92</td>
</tr>
<tr>
<td>18</td>
<td>DISCRIMINANT FUNCTIONS</td>
<td>96</td>
</tr>
</tbody>
</table>
LIST OF TABLES (continued)

19. CORRECT CLASSIFICATIONS USING DISCRIMINANT FUNCTIONS...... 101
20. EXPLAINED VARIANCE FOR COST PER HUNDREDWEIGHT OF MAIN EFFECTS AND TWO-WAY INTERACTIONS FOR SEVEN VARIABLES MODEL.................................................. 103
21. CORRELATIONS OF REGRESSION COEFFICIENTS............. 109
22. EXPLAINED VARIANCE FOR COST PER HUNDREDWEIGHT OF MAIN EFFECTS AND TWO-WAY STRUCTURES FOR SIX SYSTEM STRUCTURES AND FOR DISCRIMINANT ANALYSIS DATA............................ 110
23. EXPLAINED VARIANCE FOR DELIVERY TIME OF MAIN EFFECTS AND TWO-WAY INTERACTIONS FOR SIX SYSTEM STRUCTURES....... 113
24. NUMBER OF POOLING POINTS/WAREHOUSES....................... 114
25. EXPLAINED VARIANCE FOR DELIVERY TIME OF MAIN EFFECTS AND TWO-WAY INTERACTIONS FOR SEVEN VARIABLES MODEL...... 116
26. LOWEST COST STRUCTURES........................................ 120
27. LOWEST TRANSPORTATION COST STRUCTURES......................... 121
28. LOWEST MEAN DELIVERY TIME IN DAYS............................. 122
29. LOWEST DELIVERY TIME VARIANCE.................................. 124
30. SYSTEM STRUCTURE REGRESSED ON COST PER HUNDREDWEIGHT, DELIVERY TIME, AND DELIVERY TIME VARIANCE................. 126
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>DISTRIBUTION SYSTEM STRUCTURES INVESTIGATED</td>
<td>16</td>
</tr>
<tr>
<td>2.</td>
<td>PHYSICAL DISTRIBUTION NETWORKS</td>
<td>19</td>
</tr>
<tr>
<td>3.</td>
<td>STUDY STRUCTURE</td>
<td>56</td>
</tr>
<tr>
<td>4.</td>
<td>FLOW CHART OF RESEARCH METHODOLOGY</td>
<td>64</td>
</tr>
<tr>
<td>5.</td>
<td>MANOVA APPLICATION</td>
<td>69</td>
</tr>
<tr>
<td>6.</td>
<td>EXPLAINED VARIANCE FOR FULL AND REDUCED MODELS</td>
<td>81</td>
</tr>
<tr>
<td>7.</td>
<td>VARIABLES USED IN DISCRIMINANT ANALYSIS</td>
<td>94</td>
</tr>
<tr>
<td>8.</td>
<td>DISCRIMINANT GROUPS</td>
<td>95</td>
</tr>
<tr>
<td>9.</td>
<td>SINGULARITY OF DISCRIMINANT VARIABLES WITH GROUP VARIABLE</td>
<td>99</td>
</tr>
<tr>
<td>10.</td>
<td>TWO WAY INTERACTION: ANNUAL ORDERS AND PRODUCTS</td>
<td>104</td>
</tr>
<tr>
<td>11.</td>
<td>TWO WAY INTERACTION: MEAN ORDER WEIGHT AND PRODUCTS</td>
<td>105</td>
</tr>
<tr>
<td>12.</td>
<td>TWO WAY INTERACTION: PRODUCTS AND PLANT LOCATIONS</td>
<td>106</td>
</tr>
<tr>
<td>13.</td>
<td>TWO WAY INTERACTION: PLANT LOCATIONS AND GEOGRAPHIC DISTRIBUTION OF DEMAND</td>
<td>107</td>
</tr>
<tr>
<td>14.</td>
<td>RESULTS OF REAL DATA SIMULATIONS</td>
<td>118</td>
</tr>
</tbody>
</table>
CHAPTER I

OVERVIEW

Introduction

The motivation for this study had both theoretical and applied bases. From a theoretical perspective, research on the structure of physical distribution systems has primarily concentrated either 1) on determining the optimal number and location of warehouses or facilities or 2) on the savings of freight consolidation/pooling strategies over direct less-than-truckload (LTL) shipments of orders. Empirical comparison of these strategies does not appear in the literature. The present research compared distribution costs and delivery times for warehousing, freight consolidation, and direct LTL distribution systems for selected industrial product characteristics and demand patterns.

Economic, political, and technological factors have combined in the past decade to increase the relative importance of the logistical activities of business. Inflation in general, rising fuel costs, construction costs, high interest rates, and transportation deregulation have altered the environment to make logistics planning more difficult and more necessary. At the same time, improved logistics planning can result in greater savings than previously possible. Assistance in approaching logistics
planning has come from improvements in computer technology which permit closer monitoring of costs and more intensive analysis of logistical operations.

Some of the basic assumptions under which business is conducted changed during the past decade. No longer is energy an inexpensive resource; inflation has eroded profits and growth has slowed in many industries to the point that management cannot increase sales volume to cover rising overhead costs. \(^1\) Within a dynamic environment of changing costs and operating structures, the manager requires a method of evaluating a distribution system. Warehouses have been the basis of many systems. However, different system designs may be necessary to meet targets of improved asset productivity by reducing fixed investment in warehouses, reducing investment in inventory, or both.

The purpose of this investigation is to extend previous freight consolidation research and combine it with traditional facility location research by comparing costs and delivery times of shipments from warehouses, consolidated shipments from plants and warehouses, and direct less-than-truckload (LTL) shipments from plants in one study. The results of the research should identify conditions where freight consolidation is preferable to direct shipments from warehouse systems, where using warehouses is preferable to consolidation from plants, or where no clear advantage exists of one method of distribution over another.

Statement of the Research Issue

The premise of this research is that the relative efficiency in terms of cost and/or delivery time of traditional warehouse systems or even warehouse systems using freight consolidation strategies has not been directly compared with strategies using shipment consolidation from plants. Research is needed for two purposes. First, these alternative systems should be assessed from the standpoint of the theory of physical distribution system design. Second, an analytic framework is needed for managers to use in determining the most effective and efficient distribution system design.

As used here, both the terms freight consolidation and pooling refer to the use of pooling points which receive consolidated shipments and break them into shipments to individual customers. The term break bulk is used for this procedure. Consolidated shipments in the present research consist of two or more orders for one product class that are shipped as a single shipment to a pooling point or demand point. The terms freight consolidation and pooling are used interchangeably in this work although Newbourne and Barrett suggest that pooling implies smaller order sizes than does consolidation.²

Several models exist for determining the numbers of and locations of warehouses or facilities, such as those developed by Kuehn and Hamburger

²Newbourne and Barrett indicate order sizes under 4000 pounds would be pooled while larger, LTL shipments would be consolidated. (Malcolm J. Newbourne and Colin Barrett, "Freight Consolidation and the Shipper Part III: The Tools of Consolidation," Transportation and Distribution Management 12 (March 1972): 34-38.)
and Geoffrion and Graves.³ Mathematic solutions have been proposed by Cooper and others for various kinds of location problems such as additional facility locations and constrained warehouse capacity situations.⁴ The facility location literature contains comparisons of distribution costs of different warehouse configurations with each other and with direct shipment from sources but not with pooling systems.⁵

Freight consolidation studies by Masters and Jackson investigated the effects of using pooling points on costs and delivery time.⁶ The baseline for comparison was direct unconsolidated LTL shipments from a single plant. The results of the Masters study indicate that using a pooling strategy generally reduces transportation costs, increases mean delivery time, and either maintains or decreases delivery time variance when


⁵For example, McLaren and Whybark compared heuristic approaches of locating a fixed number of facilities in terms of computer solution time and accuracy. See B. J. McLaren and D.C. Whybark, "Comparison of Heuristic Approaches to Locating a Fixed Number of Facilities," Logistics Transactions 11, No. 4 (1975).

compared with unconsolidated shipments from a single plant. However, the
Jackson study found increases in order costs and delivery time with few
exceptions. Jackson used smaller numbers of annual orders but a larger
mean order size than the Masters study. Jackson concluded that there is
a lower bound of orders per year necessary to support a pooling strategy
for the order size and demand pattern investigated. Since Masters and
Jackson used only one product and one source for shipments, testing the
generalizability of their results to multi-source, multi-product situations
with different demand patterns seemed warranted.

From the above discussion, the study of the separate research streams
of facility location and freight consolidation does not indicate whether
pooling points or warehouse configurations are to be preferred. Thus,
the research issue of the present study is to ascertain under which demand
volumes and patterns and under which product characteristics different dis-
tribution systems may be preferred over others.

Scope of the Study

This study analyzed both simulated and actual shipment data for
high-valued industrial replenishment goods. All products were valued at
$400 per hundred weight with inventory carrying costs of 30 percent and
eight turnovers per year. A single echelon of either pooling points or
warehouses was considered. In contrast with warehouses, pooling points
incurred no storage costs although break bulk charges were assessed.
Except for consolidation of product from warehouses, combinations of dis-
tribution systems were not investigated.

Five demand and product characteristics were investigated for
their relative influence on selection of a system: total number of
annual orders, mean order weight, product classes, distribution of demand, and plant location. Total annual orders were either 50,000 or 250,000. Data consisted of order weights which were randomly determined from a normal distribution with a mean of 500 or 1500 pounds and standard deviation equal to the mean. These distributions permitted a wide range of order weights to be examined. Each order was for one product since this research assumed pooled shipments must contain only one shipment class. Multiple product orders were not explicitly modelled. The order weights were shipped as one of three products defined by shipment class.

Demand for the simulation was distributed nationally either according to population or according to manufacturers' value added. Specific demand points were either the one hundred-fifty Standard Metropolitan Statistical Areas with the highest population or the one hundred-fifty Standard Metropolitan Statistical Areas with greatest value added for specific simulations. Shipment of goods from these larger metropolitan areas to outlying areas was not included in the study from either cost or time perspectives. Nor was local delivery within the Standard Metropolitan Statistical Areas examined except when pooled shipments occurred. Direct less-than-truckload rates were assumed to include local delivery. The study, therefore, compared only distribution costs from the plant to the Standard Metropolitan Statistical Area. Neither the special requirements of government purchasing nor international demand was considered.

The freight consolidation strategies used in this research were to accumulate orders over a specific number of days and ship a consolidated order when the oldest order equalled the holding day limit or the total weight of the consolidated shipment exceeded a specified weight limit. The consolidation strategies examined were one-day and four-day holding times.
For consolidation strategies, incremental distribution costs incurred by holding orders were included. Base carrying costs were assessed at the plants and/or at the warehouses. Additional costs were included in the distribution structures using warehouses for increases in safety stock due to decentralized storage. Warehouse storage and handling costs were calculated for the distribution alternatives using warehouses, and transportation costs were calculated for all alternatives.

Warehouse and pooling points were selected from forty potential locations which represented geographically disparate Standard Metropolitan Statistical Areas for which estimates of storage and handling costs were available from industry sources.

Actual shipment data for industrial products were obtained from a division of a large corporation producing high-valued industrial equipment and parts. The data were analyzed using the same methodology as the simulation data. The results were compared to evaluate the external validity of the simulation results.

Thus, this study considered a number of alternative distribution systems for a narrow range of high-valued products whose order weights were normally distributed. Customers were located in the largest Standard Metropolitan Statistical Areas by population or manufacturer's value added. These conditions and systems were selected because they were typical, though not comprehensive, of existing and potential distribution systems.

**Research Questions**

The research objective was to identify which combinations of demand and product characteristics indicated pooling or warehouse configurations
or whether there was no clear choice. This objective suggested the following research questions:

1. What is the effect of A) pooling orders from plants, B) consolidating orders shipped from warehouses, C) shipping direct from warehouses, or D) shipping direct from plants on 1) distribution costs and 2) delivery time? Specifically, a) Is a direct unconsolidated shipment structure significantly more expensive than the other structures? b) Is mean delivery time for structures using consolidation significantly greater than mean delivery time for structures not using consolidation? And c) do consolidation strategies significantly increase delivery time variance?

2. For what levels of the independent variables studied is the use of pooling points preferable to warehouse distribution systems?

3. What demand, product, and system structure characteristics are most important in determining distribution costs?

Methodology

The research questions were investigated through the use of simulation and the general linear model. An event-oriented Monte Carlo simulation was used to determine the distribution costs and delivery times for a number of different product and demand characteristics of industrial goods. A simulation was run for six distribution system structures at each combination of product and demand characteristics. To gain an understanding of the relative influence of product and demand characteristics and system structure on costs, regression analyses were performed on the results of the simulations. A brief discussion of the variables considered, the stages of the research project, and potential limitations of the methodology follows.
Variables

Dependent

Distribution costs, delivery times, and delivery time variances were computed for each of six distribution system structures for different combinations of product and demand characteristics. Total system delivery costs were necessary since using pooling points would not include the fixed costs of the warehouse structures. The delivery time mean and its variance are measures of customer service level.

Independent

The major variable under investigation was system structure. The six different structures which vary on a) whether freight consolidation is used, and b) whether warehouses are used are defined in figure 1. Product and demand variables which appeared to influence distribution costs and delivery times from previous research include total number of annual orders, order size, product class, geographic distribution of demand, and plant location.

Outline of the Research Project

The research involved four steps: 1) determination of the best configurations for the system structures for each combination of product and demand characteristics, 2) simulation of the system structures, 3) determination of the least cost structure for each product and demand combination, and 4) discriminant analysis and regressions on the simulation results to determine which factors investigated had the strongest relationships to costs of different structures and to predict lowest cost system structures subject to a service level constraint.
<table>
<thead>
<tr>
<th></th>
<th>No Consolidation</th>
<th>Consolidation</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0 days</td>
<td>1 day</td>
</tr>
<tr>
<td></td>
<td>Holding time</td>
<td>Holding Time</td>
</tr>
<tr>
<td>Shipments from plants</td>
<td>plant-0 days</td>
<td>plant-1 day</td>
</tr>
<tr>
<td>only</td>
<td>holding time</td>
<td>holding time</td>
</tr>
<tr>
<td>Shipments from warehouses as well as plants</td>
<td>warehouse-0 days holding time</td>
<td>warehouse-1 day holding time</td>
</tr>
</tbody>
</table>

Figure 1. Distribution System Structures Investigated.
The first step was basically a location analysis problem which was solved using Khumawala's algorithm. The second step was accomplished by the use of event-oriented Monte Carlo simulation models, including a freight consolidation algorithm, for calculating distribution costs and delivery times.

In the third step, a multivariate analysis of variance was performed for each combination of product and demand characteristics across the six distribution system structures to determine whether the costs or the delivery times were statistically different. To find the lowest cost system structures and to test the research hypotheses, pairwise post hoc comparisons were conducted if the null hypothesis of no difference was rejected. Discriminant and regression analyses were employed in the fourth step to study the relative importance of demand and product characteristics to distribution costs. Additionally, a regression analysis using all results was used to indicate the importance of system structure in determining distribution costs.

Limitations

The potential limitations of the study occur because of the test environment, the focus of the study and extensions of results, and the specific analyses. The reader is advised of these limitations at this point to help avoid misinterpretation of the results of the study.

Test Environment
The use of modelling instead of studying real systems directly can raise several questions regarding the validity of the results. Validity of the simulation can be evaluated against actual performance data. A second means of collaborating model validity is to compare the model formulation with other distribution model formulations. The model in this research uses the same relationships as the House model and is similar to the Kuehn and Hamburger and to the Geoffrion and Graves models.\textsuperscript{8} Masters' freight consolidation algorithm is used for the pooling strategies.\textsuperscript{9}

Focus of The Study and Its Generalizability
The results of this study should not be generalized beyond the assumptions and factor levels investigated. The research has relied on previous studies in selecting the variables and levels of variables for inclusion. However, in attempting to select the most important variables the potential for excluding a relevant variable as well as the possibility of including irrelevant variables exists.

Statistical Analysis
The statistical techniques used in this investigation are based on relative variation in the factors being investigated and the assumptions of normality of data and homogeneity and independence of error variance. Thus, the results are dependent to some extent upon the amount of variation across the levels of each factor. The number and values of the

\textsuperscript{8}Kuehn and Hamburger, "A Heuristic Program;" Geoffrion and Graves, "Multicommodity Distribution System Design."

\textsuperscript{9}Masters, "The Effects of Freight Consolidation."
levels were chosen to represent realistic variations to avoid undue bias. The hypothetical demand data were generated to conform to the assumptions.

Potential Contributions

Theoretical

The potential contributions to the logistics field are 1) extending the freight consolidation literature and 2) comparing different distribution structures. This research extends previous freight consolidation research by examining more than one product and one source and by investigating an industrial demand distribution in addition to a consumer products demand distribution. The generalizability of the conclusions of previous freight consolidation research concerning relative cost and delivery time is studied. For example, consolidation has often been considered a solution to the small shipment problem.\textsuperscript{10} Products with larger mean order sizes in relation to total demand than those already studied may not experience the same cost benefits as occurs with mean shipment sizes of about 1000 pounds or less. However, a consolidation strategy may still be preferable to a warehousing strategy. Thus, this research may contribute information to assist in building a theory of freight consolidation feasibility.

The second potential theoretical contribution is that this research merges two separate approaches to determining physical distribution system structure: fixed facility location analysis and freight

consolidation analysis. Previous research efforts have concentrated on one area or the other. In order to arrive at more comprehensive theories regarding optimal physical distribution system design, a comparison of the two approaches seems necessary. Direct comparison of different system structures indicates the relative advantages in cost and service. Examining a range of product and demand characteristics provides insight into the generalizability of the comparisons of system structure.

Methodology

While the statistical techniques used in this research are not new, the multi-product, multi-source consolidation model and the methodology for comparing the different systems constitute a contribution to the field of logistics research. Masters' and Jackson's models simulate one product and one source. The methodology for evaluating system structures is rigorous in that it utilizes several techniques sequentially to select and compare the alternative system structures. First, an optimization model was used to select the best warehouse or pooling configuration; multivariate analysis of variance was used to account for experimental error when testing whether cost and delivery time differed significantly across system structures. Finally, discriminant and regression analyses were used to examine cost relationships.

Application

The results of this research can assist distribution managers' evaluations of whether a pooling strategy should be considered. Specifically, a manager can assess the relative merits of different system

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structures. If there are significant differences in distribution cost for a relevant combination of product and demand characteristics, then management can be aware that the structure used to distribute the products affects the costs.

Direct comparison of distribution systems using warehouse configurations with freight consolidation strategies has not been available in the literature. While the results should not be generalized beyond the specific ranges of product and demand characteristics studied, the broad range that is included should apply to many situations.

Organization of the Dissertation

The next two chapters contain the literature review and the research methodology. In Chapter II, the concept of a distribution system is discussed first to provide a common vocabulary for the remainder of the work. The warehouse location and freight consolidation literatures are then examined to establish that previous research has not compared the two strategies for developing distribution system structure. Chapter III contains the research hypotheses and methodology for examining the research questions posed. Chapter IV reports the results of the study including the hypothesis tests and additional findings from the discriminant and regression analyses. Chapter V concludes the dissertation with a summary of the research effort, conclusions and implications drawn from the results, and suggestions for additional research based on the results of this study.
CHAPTER II

LITERATURE REVIEW

Purpose and Scope

The purpose of Chapter II is to review both warehouse location and freight consolidation literatures for evidence of previous comparison of the two distribution system designs. Means of studying this issue are examined as well as identification of gaps in previous research which the current research will address. First, a discussion of methods and approaches to studying systems provides the reader with a background for the literature to be reviewed. The background material consists of identifying the components of any system to be studied and relating these components to the elements of a physical distribution system. Once a common frame of reference is established for studying systems, the potential objectives of systems are presented to indicate their conflicting effects on determining optimal systems. For example, the least cost objective may result in a very different system from that which gives the fastest delivery time. The warehouse location and freight consolidation literatures are then examined. Representative models are presented to demonstrate the modeling approaches and assumptions for locating warehouses or pooling points. Their specific formulations are in Appendices A-D.
The organization of this chapter consists of providing a brief background in systems theory, examining means of investigating the research issue, reviewing the warehouse location and freight consolidation literatures, and identifying gaps in previous research. First, the application of systems theory to the study of physical distribution and measures of system performance are presented.

**Systems Theory and Physical Distribution**

The systems approach to studying natural phenomena or business situations is not new.\(^1\) The natural and applied sciences, and particularly engineering have employed the concept of flows of entities through various conditions. The similarities across disciplines have led operations researchers to define the components of any system to be of four kinds: 1) entities, 2) attributes, 3) activities, and 4) state.\(^2\) Entities are the objects that proceed through a system, such as people, water, or goods through a physical distribution system. Attributes are the characteristics of the entities, such as weight of the product. Activities are processes that change a system, such as filling an order. The state of a system can refer to whether a facility is busy or idle. Thus, any "system" can be defined in terms of these four characteristics.

In a physical distribution system, the flow of product is often depicted by nodes which are plants, warehouses, or pooling points, and


links between these nodes. Entities travel between nodes and can be handled and/or stored (activities) at the nodes. Examples of a single echelon of warehouses and a direct distribution system using nodes and links are provided in figure 2. The performance of a system can be measured in terms of costs or time or social value. Several authors in the field of physical distribution have identified the activities which require varying amounts of cost and time. Tables 1 and 2 list the suggestions of LaLonde, et al., and Ballou.

Means of Studying Physical Distribution Systems

The use of field experiments which modify actual operating conditions is generally not feasible for studying physical distribution systems because of 1) potential destructive side effects, 2) the time required and 3) the limited range over which some factors can be varied. Thus, the literature reviewed here is of a modelling nature. This section discusses the choices available to the modeller in creating a system for investigation.

The nature of the variables to be studied will have a bearing on model selection. Bowersox proposed a classification scheme, provided in Table 3, for physical distribution models based on the independent and dependent variables to be included. Other classification schemes and criteria for models are proposed by Geoffrion in Table 4 and House and Karrenbauer in Table 5. The proposals indicate a need for identifying the purpose for which the model is constructed, the extent to which the model approaches a real system, and the requirements for the output from
ONE ECHelon OF WAREHOUSES

DIRECT SHIPMENT

Figure 2. Examples of small echelon of warehouses and direct shipment of each plant.
Table 1

LOGISTICS SYSTEM COMPONENTS: EXAMPLE 1

A. Facilities Location  
B. Purchasing  
C. Packaging  
D. Production Control  
E. Materials Handling  
F. Warehousing and Storage  
G. Inventory Control  
H. Traffic and Transportation  
I. Order Processing  
J. Distribution Communications  
K. Parts and Service Support  
L. Personnel Movement  
M. Returned Goods  
N. Salvage and Scrap Disposal  
O. Customer Distribution Programs  
P. Vendor Distribution Programs

Table 2

LOGISTICS SYSTEM COMPONENTS: EXAMPLE 2

I. Key Elements

A. Transportation
   1. mode and service selection
   2. carrier routing
   3. vehicle scheduling

B. Inventories
   1. finished goods stocking policies
   2. record keeping
   3. supply scheduling (purchasing)
   4. short-term sales forecasting

C. Customer Service--Cooperate With Marketing In
   1. determining customer needs and wants for service
   2. determining customer response to service

D. Order Processing and Information Flows
   1. sales order procedures
   2. information collection, storage, and manipulation
   3. data analysis

II. Supporting Activities

A. Warehousing
   1. space determination
   2. stock layout and dock design
   3. stock placement
   4. warehouse configuration

B. Materials Handling
   1. equipment selection
   2. equipment replacement policies
   3. order picking procedures
   4. stock storage and retrieval

C. Protective Packaging--Design For
   1. handling
   2. storage
   3. protection

D. Product Scheduling--Cooperate With Production In
   1. specifying aggregate production quantities
   2. sequencing and timing of production
Table 2 (continued)

E. Facility Location
   1. determining location, number and size of facilities needed
   2. allocating demand to facilities

Table 3
LONG RANGE ENVIRONMENTAL PLANNING SIMULATION
CLASSIFICATION SCHEME
PHYSICAL DISTRIBUTION SYSTEM MODELS

I. PROBLEM DEFINITION: THE INDEPENDENT VARIABLES

A. Type and Number of Physical Distribution Components
   1. Single component
   2. All components

B. Planning Horizon
   1. Short Range (operational)
   2. Long Range (strategic)

C. Influence by Previous Decisions
   1. Non-sequential
   2. Sequential

II. APPROACH TO SOLUTION: THE DEPENDENT VARIABLES

A. Type of Technique
   1. Analytical (optimization)
   2. Heuristic (simulation)

B. Unifying Dimension
   1. Spatial (distance or location)
   2. Temporal (time)

C. Behavior of System Model
   1. Static
   2. Dynamic

D. Environmental Inputs
   1. Fixed over planning period
   2. Variable over planning period

Source: Bowersox et al., Dynamic Simulation of Physical Distribution Systems (East Lansing, Michigan: Division of Research, Graduate School of Business Administration, Michigan State University, 1972).
I. IMPORTANT PROBLEM FEATURES TO BE MODELED

A. Multiple Products
B. Two Stages of Distribution: Plants to Warehouses and Warehouses to Customers
C. Capacities for Plants and Size Limits for Warehouses
D. Warehouse Economies of Scale and Fixed Charge
E. Each Customer Serviced by a Single Warehouse
F. Shipments to Customers: Preserve the Identity of Originating Plants
G. Various Desired Constraints on Distribution System Configuration

II. ESSENTIAL CRITERIA FOR A USEFUL COMPUTATIONAL METHOD

A. It Should Truly Optimize
B. Computer Costs Should Be Moderate
C. The Computational Method Should Facilitate Multiple Secondary Optimization Runs

I. THEORETICAL REQUIREMENTS

A. The representation should not violate viable theoretical conceptualization of the logistics system unless its superiority to previous theory can be demonstrated.

B. The model should be applicable to a large number of logistics situations. It should represent adequately the wide variety of configurations that can be observed in operation.

C. The model should parsimoniously but accurately represent reality.

D. The model should optimize the system structure according to the appropriate goal set. Because system goals can vary widely, the model should be capable of identifying optimality conditions under alternative goals without extensive reformulation.

II. PRACTICAL CONSIDERATIONS

A. The model should be computationally feasible.

B. The model should indicate directions of desired future change.

C. The model should identify an adjustment path to follow in moving from the current system to the optimal one.

D. The model should evaluate the system's ability to absorb various short run fluctuations in the desired output of the system.

the model. The different model characteristics are presented here to facilitate the discussion of the literature.

Distinctions of interest are: 1) static-dynamic, 2) stochastic-deterministic, 3) optimization-simulation, and 4) one product/one plant versus multi-product/multi-plant models. The location models to be discussed are static models which assume the relationships are the same over the period investigated. Dynamic models, in contrast, are time-dependent and attempt to model a system over time as in simulating a one-year operating period. Time-dependent variables in the system require that the model be dynamic unless some previous research has suggested mean values and measures of variation for the variables.

Some elements of a system can be represented by random variables with particular means and variances. The number of orders received on a particular day is often distributed as a random variable. In contrast, variables which can be represented by specific values are labeled deterministic, and if all the variables in the equation are deterministic, the model is said to be deterministic. Otherwise, it is stochastic.

If the objective of the research is to minimize cost or determine the configuration for a certain level of customer service, then some form of optimizing technique is in order. However, if the purpose of the study is to investigate the behavior of a system under certain conditions then a simulation project may be useful. The term simulation is used in the very broad sense of replicating a system or merely calculating performance values using Monte Carlo techniques.

Several of the investigations to be reported in the remainder of this chapter involve only one plant and one product. For many companies this may be sufficient if only one product accounts for a majority of the
sales. In other distribution situations, modeling more than one plant and one product may be required.

With this information in mind, the discussion now turns to identifying potential measures of system performance.

**Measures of System Performance**

System performance can be evaluated on the basis of costs and customer service elements such as order cycle times. A number of measures of system performance can be suggested for each component of the system. Cost can be evaluated as total cost, cost per hundredweight (cwt), cost per order, cost per customer. Delivery time can be similarly defined.

Costs can be reported in terms of individual elements of a system such as transportation costs. However, for system cost reduction, analysis cannot be limited to studying individual element costs. The total cost approach suggests that total system costs must be evaluated as well as these individual element costs. The rationale for this requirement is that minimizing costs of one element may result in offsetting increased costs of another element. Reducing inventory safety stocks may cause increased stockouts resulting in more emergency orders at higher shipping costs. There are many tradeoffs within the distribution system.

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and all elements of the system must be considered to ensure a truly lowest overall cost system.

A composite measure of system performance suggested in the literature is customer service. This term can consist of several performance criteria. LaLonde and Zinszer suggest the following components of customer service:

1. Product availability - the probability that a given product will be available when an order is placed.

2. Order cycle time - the elapsed time between when an order is first placed by the customer and receipt of the entire order.

3. Distribution System Flexibility - ability to expedite, to backorder, to substitute a product, to use faster transportation.

4. Distribution System Information - inventory and order status, forecasting ability.

5. Distributing System Malfunction - errors: administrative, picking, shipping; damage: warehouse, company, carrier.


Others have suggested similar lists of components of customer services.  

Since customer service consists of many different activities, there must be several measurements, most of which are in terms of time, due to the nature of the components themselves. Bowersox suggested several measures for customer service: 1) average delivery time,

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2) standard deviation of delivery time, 3) distribution of orders within time intervals, 4) percent of orders within time intervals, 5) dollar value of orders within time intervals, 6) percent of order dollar value within time intervals.  

Lowest total cost and high customer service level can be competing objectives since higher inventories are needed to ensure product availability to maintain a high service level and, thus, higher costs are incurred. The concept of total profit incorporates the tradeoffs between total cost and customer service.  

Lost sales from lower customer service levels are charged against the costs of operating the system. A problem with the total profit approach is estimating the cost of lost sales.

Distribution systems can be constructed with different configurations of warehouses or consolidation points to 1) minimize costs, 2) to maximize customer service, or 3) to achieve some combination of these system performance measures. The system which minimizes cost may also lower customer service levels; the system delivering the best service in terms of shortest mean delivery time or lowest delivery time variance may result in higher system costs. Thus, achieving an optimal system design is often difficult without setting a minimum service level or a maximum cost and solving for the other objective.

Another system objective which is not addressed here is minimum distance from all customers which is most often found in the location of

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public emergency facilities such as hospitals or fire stations. Clearly, different performance criteria may result in different distribution configurations.

Now that the elements of a distribution system, measures of system performance, and difficulties of conflicting performance objectives have been discussed, the main topic of reviewing the warehouse location and freight consolidation literatures is addressed.

Warehouse Location and Freight Consolidation Literature

The warehouse location and freight consolidation literature review is divided into three sections: 1) both literatures were searched for evidence of previous comparisons of warehousing systems with consolidation systems, 2) examples of model formulations for warehouse location problems are presented, and 3) freight consolidation literature was reviewed. The first section supports the need for the current research; the second section indicates the methods which have been used to solve the warehouse location problem for multi-source, multi-product systems; the third section reports the conclusions of previous freight consolidation research which the current research extends.

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9The work of Masters indicated that different objectives yielded different configurations. James M. Masters, "The Effects of Freight Consolidation on Transportation Costs and Delivery Times in a Physical Distribution System,"(Ph.D. dissertation, The Ohio State University, 1979).
Comparisons of Different System Structures

Facility location literature is quite extensive and has been developed by researchers in operations research, mathematics, engineering, geography, and business. Warehouse location models are a subset of facility location models which have costs associated with opening and/or using a warehouse and may permit different transportation costs per unit for the plant-warehouse, first leg, distances other than for the warehouse-customer, second leg, distances. Locating pooling points for freight consolidation systems can be viewed as warehouse location problems with small or no fixed costs occurring at the pooling points and transportation rate differences for the first and second legs. The warehouse location solution methods can be applied to freight consolidation with modifications to account for the time dimension of pooling of orders. Viewed from this perspective, one might expect to find many comparisons of warehouse location and freight consolidation strategies. However, this review has not found any such comparisons.

The warehouse location works discussed in the next section report final solutions, prove optimality from a mathematical standpoint, or indicate speed of convergence or usefulness of heuristic approaches. Such investigations imply that the particular solution is better than unconsolidated, direct shipment from plants, the zero field warehouse situation, but few researchers have published such comparisons. Markland compared zero through five field warehouse solutions using a computer simulation and found the zero warehouse case to be most expensive.\textsuperscript{10}

Published information about use of the models does not indicate any consideration of using pooling points. A portion of the location literature addresses locating a predetermined number of facilities or adding a certain number of new facilities to an existing network of facilities. In these cases the choice of using no fixed facilities was not investigated.

The freight consolidation literature is small, compared with the warehouse location literature. Consolidation literature consists of descriptions for the small shipment problem, suggestions for implementing consolidation and a few empirical studies. These are discussed in the consolidation literature review. However, as with warehouse location, no attempts have been made to compare the two strategies.

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directly. One possible explanation for the lack of comparisons is the relatively recent appearance of consolidation models. The first was presented by Lai and LaLonde.\textsuperscript{13} Rising transportation costs since the first oil embargo in 1973-74 may have escalated the interest in freight consolidation to reduce small shipment costs. Thus, the freight consolidation literature is only now developing and concentration has been on building models instead of comparing consolidation models with other distribution models. Since evidence of direct comparison of warehouse location and freight consolidation has not been found in the literature, the discussion moves to examining each strategy separately to establish a basis for such a comparison.

\textbf{Approaches to Facility Location}

Solutions to the facility location problem have come either 1) from statistical mathematical solutions or some form of mathematical programming to achieve an optimal solution, or 2) from heuristic algorithms and simulation to obtain good solutions or to obtain understanding of system costs and flow. In addition, solutions can be further tailored to fit specific conditions such as constrained capacities on plants or warehouse locations. Since the current research is considered in the long term planning mode, capacity constraints are not included. Optimization techniques and models are discussed first, followed by heuristic methods.

Optimization

Cooper and Drezner and Weslowsky provide mathematic proofs of optimal warehouse location in continuous space.\textsuperscript{14} Effroymson and Ray offer the earliest mathematic programming solution using branch and bound for warehouse location.\textsuperscript{15} Ostresh,\textsuperscript{16} Khumawala\textsuperscript{17}, and Green, Kim and Lee\textsuperscript{18} have also used branch and bound. Khumawala improved the original approach by adding computer efficiencies to the mixed integer programming solution algorithm. His formulation, which requires fixed and variable costs of shipping to each customer through each warehouse, is provided in Appendix A. Erlenkotter\textsuperscript{19} and Jucker and Carlson\textsuperscript{20} also used mixed integer programming but did not use the branch and bound algorithm.


Geoffrion and Graves developed an optimization model using mixed integer linear programming and Bender's decomposition method in combination with a bounding methodology. The original formulation has been improved and now incorporates a primal transshipment algorithm described by Bradley, Brown and Graves.\textsuperscript{21} A master problem formulates a potential solution which is submitted to a set of transportation sub-problems. The sub-problems are solved using the transshipment algorithm and a potential solution is returned to the master problem. The model iterates until the solutions of the master problem and sub-problems are within a specified tolerance. The master problem solution provides a lower bound while the sub-problems provide the upper bound of the optimal solution.

The objective of the model is to minimize total cost. No direct penalty is included for minimum service levels for products. Inbound and outbound transportation costs may be included with an increment for transit inventory considerations. Thus, Geoffrion and Graves assume an interdependency between transportation costs and transit inventory costs. Fixed and variable costs are included additively with upper and lower bounds on throughput for each facility. Variable costs by warehouse by product bundle are possible. Products are not considered individually.

but are aggregated into bundles to reduce the magnitude of the problem to be solved. The model does permit a customer to receive different products from different warehouses. A list of of the variables in the model and its formulation are in Appendix B.

Heuristics and Simulation

Heuristic approaches have been suggested by Kuehn and Hamburger, Cooper, Rushton and Kohler, Shycon and Maffei, McGregor and Shen, Eilon and Galvao, Maranzana, Teitz and Bart, and Markland. The Maranzana and the Teitz and Bart methods select a specified number of warehouse locations. The Maranzana heuristic involves randomly constructing a configuration of facilities, assigning customers to zones serviced by one facility, and then iteratively improving on the solution, creating new zones as necessary, until no improvement is possible. By performing this

procedure many times and using only the best solution from all the runs, a very good solution is achieved.

**Kuehn and Hamburger Heuristic Model**

One of the early modelling approaches to location analysis uses a sequential heuristic method of selecting one facility at a time. Potential locations are added to the solution configuration one at a time until no additional savings occur from adding a warehouse. This may lead to a local optimum. The configuration is then reviewed to determine if a location already in the solution set should be dropped and if warehouse locations should be moved to achieve a lower cost of distributing the products. The model includes a penalty cost for delaying a shipment which constitutes a minimum service level in terms of time. A delay in terms of time units is permitted before the entire variable assumes an infinite value. Appendix C contains a detailed definition of the relationships of the elements in the model. Separate inbound and outbound transportation costs, fixed and semi-variable warehouse costs, and the minimum service level constraint are considered as independent variables in the model in an additive relationship.

**House Simulation Model**

House developed a model to calculate total distribution costs from a prespecified distribution configuration. The model has a straightforward solution logic so that a manager can easily understand the

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calculations. The model assumes the user is knowledgeable about the system being investigated and should have an idea which locations are good candidates for inclusion in the configuration. Components of the model include inbound and outbound transportation costs and fixed and variable costs by warehouse. Only one variable cost per warehouse is used instead of variable costs by location by product. No customer service estimates are included. Appendix D provides the model formulation.

House's model is capable of assigning customers and products to warehouses to minimize total cost of the configuration supplied by the user. An additional capability is direct shipments from the plant to the customer if the size of the order permits truckload or carload rates. Thus, the model is flexible for investigating a combination of distribution strategies as well as the traditional shipment of product from warehouse to customer. Multiple products, plants and modes of transportation are possible.

**Summary of Approaches to Warehouse Location**

The location of distribution facilities affects practically all aspects of the system. Different configurations may have different transportation cost structures and customer service levels from supply points to customers and different costs of maintaining and operating facilities in different parts of the country due to differing land, labor, and utilities costs. The manner in which number and locations of facilities are determined is based on the assumed relationship of the parts of the distribution system as well as the model objectives. Four examples of formulations of the location problem have illustrated optimization and heuristic methods.
Freight Consolidation Research

The potential for savings through the use of freight consolidation has received attention in recent years with the increase in transportation costs, particularly because of the small shipment problem. Small shipments are charged considerably higher rates than full truckload shipments and this difference may widen with freight deregulation. In the mid-1970's trucking companies indicated they were losing money on shipments of less than 500 pounds before deregulation. At that time approximately 75 percent of all orders trucked were moved in less than 1000 pound shipments which represents approximately 35 percent of total weight shipped. The average weight of small shipments is approximately 100 pounds.

Consolidation can occur across time, customers, and/or products. The possibility of pooling shipments to a customer zone at truckload rates or at least larger shipment sizes could substantially reduce


27 Small shipments are defined as less-than-truckload and less than 10,000 pounds in Small Shipments a Matter of National Concern prepared for the Department of Transportation by the American University, School of Business Administration, (Washington, D.C.: Transportation Research Center, 1974): 4 and 27.
transportation costs. However, customer service levels defined as order cycle time might be substantially increased if shipment of some orders were delayed until enough orders accumulated for a large shipment at lower transportation rates. Consolidation across products usually occurs if products fall into the same freight class or if a freight-all-kinds rate is negotiated.

Newbourne and Barrett outlined from the shipper's standpoint considerations for pooling and suggested direct computations of rates between points to determine potential savings from pooling.28 Newbourne later provided a small, time-sharing computer program for calculating "rough cut" transportation costs for direct shipment and pooling based on the shipper's estimates of the percent of volume shipped at less-than-truckload rates.29 Schuster studied the costs of LTL shipments to carriers and concluded that carriers did not provide incentives for shippers to adopt strategies which would reduce the carriers' cost of handling small shipments.30 Research efforts by Lai, Masters and Jackson have


30Allan D. Schuster, "An Econometric Analysis of Motor Carrier Less-Than-Truckload Transportation Services."
directly investigated the effects of freight consolidation on costs and delivery time via simulation. More recently Brennan has approached consolidation from a strictly mathematical perspective.

Simulation Approaches

Lai Single Public Warehouse Regional Distribution Model

A concern for assisting public warehousemen in consolidating orders shipped from their warehouses to customers prompted Lai to develop a computer model to simulate orders over a period of one month with the assumption that some shipments must be made daily.\textsuperscript{31} He made comparisons to determine whether savings resulted from consolidation of orders considering stop-off and cross-docking charges. The order was either consolidated, shipped alone, or held for another day up to a maturity cutoff. This study evaluated the costs of shipments from a warehouse to a limited geographical region. Conclusions of the study indicated that 1) greater savings resulted when smaller shipments were involved, 2) savings were relatively insensitive to length of holding period, and 3) savings were moderately sensitive to increases in transportation costs.

Single Product-National Distribution Models

Masters

Masters studied the effects of pooling shipments on customer service measured in mean delivery time and delivery time variance.\textsuperscript{32} He also

\begin{footnotesize}

\textsuperscript{32}James M. Masters, "The Effects of Freight Consolidation on Customer Service,"
\end{footnotesize}
collected total transportation costs. The model was stochastic and dynamic, simulating one year of orders for one product produced from one plant and shipped nationwide. Demand was distributed according to population; hence, the results are particularly applicable to consumer goods. A full factorial experiment included number of orders, order size, network design criterion, number of consolidation points, and maximum holding time. Table 6 explains the levels of the design. Specific order weights were drawn from a normal distribution with a mean equal to the level under investigation and a standard deviation equal to one-half of the mean. The number of orders received per day from a demand point was a poisson random variable of average daily orders from the demand point.

Configurations for the pooling points were heuristically selected to achieve lowest costs, shortest delivery time, or smallest delivery time variance. Since the networks designed to meet each of the criteria were statistically different from each other, the study suggests that a good configuration for lowering costs is substantially different from a design to improve customer service.

Results of his investigation indicate that costs are reduced, mean delivery time is increased, but delivery time variance is not increased when shipments are consolidated rather than shipped direct and unconsolidated. Table 7 contains the explained variance using the $\omega^2$ statistic from analysis of variance. Order weight was always the most important factor for each dependent variable of cost, delivery time, and delivery time variance. The number of orders and the design algorithm were important in explaining mean delivery time while number of orders accounted for much of the variance in delivery time. Since only one product and
Table 6
Experimental Design: Specification of Factor Levels
Masters' Study

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>Factor Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>A. Total Throughput</td>
<td></td>
</tr>
<tr>
<td>Volume (annual orders)</td>
<td>500,000</td>
</tr>
<tr>
<td>B. Mean Order Size</td>
<td>100 lbs.</td>
</tr>
<tr>
<td>C. Network Design</td>
<td></td>
</tr>
<tr>
<td>Criterion</td>
<td>transport cost</td>
</tr>
<tr>
<td>D. Number of Consolidation Points</td>
<td>60</td>
</tr>
<tr>
<td>E. Maximum Holding Time</td>
<td>7 days</td>
</tr>
</tbody>
</table>

Table 7
Summary of Main Factor Effects - Masters
(Percentage of Explained Variation)

<table>
<thead>
<tr>
<th>Effect of:</th>
<th>On Dependent Variable:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transport Cost</td>
</tr>
<tr>
<td>A. Annual Orders</td>
<td>2.7%</td>
</tr>
<tr>
<td>B. Order Weight</td>
<td>93.9</td>
</tr>
<tr>
<td>C. Design Algorithm</td>
<td>0.7</td>
</tr>
<tr>
<td>D. Consolidation Points</td>
<td>Negligible</td>
</tr>
<tr>
<td>E. Holding Time Rule</td>
<td>1.0</td>
</tr>
</tbody>
</table>

one plant were assumed, the generalizability to multiple products and 
supply points has not been established.

Jackson

In a similar experiment Jackson collected information on total order 
costs, mean delivery time, and delivery time variance.\textsuperscript{33} He also assumed 
one product, one plant, and nationwide distribution. Instead of investigat-
ating different design criteria as Masters did, Jackson varied shipment 
release strategies by using either scheduled shipping dates or a combina-
tion of scheduled shipping and a volume requirement. The factors and 
levels for the full factorial research design are listed in Table 8. 
Jackson simulated over a shorter period of time, 120 days, than Masters 
did, and drew order sizes from an empirical distribution with a mean 
weight of 1300 pounds. The distribution was skewed toward smaller orders.

The maximum number of days an order could account for the 
most variance in order costs, as Table 9 indicates. The number of annual 
orders was second most important. The other variables and interactions 
each explained six percent or less of the variance. Mean delivery time 
increased with an increase in holding time except for four holding days 
when delivery time decreased. A major finding of the study was that con-
solidation is not really practical at low order volumes. National ship-
ments of 12,500 orders per year tended to be more expensive than shipment 
of 50,000 orders per year. The lower volume of orders was particularly 
penalized on mean delivery times and variances since orders would be held

\textsuperscript{33}George C. Jackson, "An Experimental Investigation of the Order Con-
solidation Problem," Ph.D. dissertation, The Ohio State University, 1980.)
Table 8
Experimental Design Jackson Study

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

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

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

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

Source: Jackson, An Experimental Investigation.
Table 9
EXPLAINED VARIANCE OF JACKSON STUDY  
(Dependent Variable: Cost)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Explained Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holding Time</td>
<td>44 %</td>
</tr>
<tr>
<td>Number of Orders</td>
<td>29</td>
</tr>
<tr>
<td>Number of Pooling Points</td>
<td>6</td>
</tr>
<tr>
<td>Shipment Strategy</td>
<td>.4</td>
</tr>
<tr>
<td>Holding time X Number of Pooling Points</td>
<td>3</td>
</tr>
<tr>
<td>Number of Orders X Shipment Strategy</td>
<td>4</td>
</tr>
<tr>
<td>Number of Orders X Number of Pooling Points</td>
<td>3</td>
</tr>
<tr>
<td>Number of Pooling Points X Holding Time X Shipment Strategy</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Calculated from analysis of variance table 4-1, Jackson, An Experimental Investigation, p. 149.
longer for accumulation without obtaining enough volume to receive better shipping rates.

The Masters and Jackson studies fit together in terms of volume of orders with an overlap of 50,000 orders per year. The mean delivery times and variances for the 50,000 order category differ for the two studies, perhaps because of different distribution networks, order sizes, and number of pooling points. Selected results of the two studies for delivery time means and variances and explained variance are presented in Tables 10 and 11. The cost figures are not directly comparable since Masters used transportation costs and Jackson reports ordering costs.

Mathematic Approach - Brennan

Brennan studied existing mathematical approaches from inventory and renewal theory for application in determining length of holding time and minimum release weight of accumulated orders.\(^3^4\) His work considered a single product class and one customer with consolidation over time only. No intermediate pooling points were permitted for consolidation across customers.

Mathematical approaches were suggested for determining the optimal shipment quantity and accumulation time for the equivalent of the deterministic and stochastic demand situations in inventory theory. The time and quantity decisions can be viewed as the reverse of the classic inventory situation. Instead of receiving the economic order quantity and having that amount reduced through use, the consolidation situation accumulates orders up to an economic shipment quantity and then ships all orders as a single shipment.

Table 10
Costs, Delivery Time Means and Variances for Masters and Jackson Studies

<table>
<thead>
<tr>
<th>Number of Arrival Orders</th>
<th>Average Weight of Order</th>
<th>Number of Pooling Points</th>
<th>Cost - Average Cost/Order</th>
<th>Mean Delivery Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jackson¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12500</td>
<td>1300 lbs.</td>
<td>10</td>
<td>$153.08</td>
<td>8.36</td>
</tr>
<tr>
<td>12500</td>
<td>1300 lbs</td>
<td>30</td>
<td>166.79</td>
<td>8.64</td>
</tr>
<tr>
<td>50000</td>
<td>1300 lbs</td>
<td>10</td>
<td>145.49</td>
<td>8.04</td>
</tr>
<tr>
<td>500000</td>
<td>1300 lbs</td>
<td>30</td>
<td>150.97</td>
<td>8.38</td>
</tr>
<tr>
<td>Masters²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500000</td>
<td>1000 lbs</td>
<td>20</td>
<td>$10.36</td>
<td>7.20</td>
</tr>
<tr>
<td>250,000</td>
<td>1000 lbs</td>
<td>60</td>
<td>9.83</td>
<td>7.17</td>
</tr>
<tr>
<td>500,000</td>
<td>1000 lbs</td>
<td>60</td>
<td>9.78</td>
<td>6.67</td>
</tr>
</tbody>
</table>

¹Using the scheduled sailing strategy.
²Figures are for systems designed to minimize cost.

Sources: Jackson, An Experimental Investigation, pp. 186-187; Masters, "The Effects of Freight Consolidation on Customer Service," p. 68.
Table 11
EXPLAINED VARIANCE OF MASTERS AND JACKSON STUDIES

<table>
<thead>
<tr>
<th>Effect</th>
<th>Number of Levels</th>
<th>Range of Levels</th>
<th>Explained Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Masters</td>
<td>Masters</td>
<td>Masters</td>
</tr>
<tr>
<td></td>
<td>Jackson</td>
<td>Jackson</td>
<td>Jackson</td>
</tr>
<tr>
<td>Number of Annual Orders</td>
<td>3</td>
<td>50M-250M</td>
<td>2.7%</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>125M-50M</td>
<td>31%</td>
</tr>
<tr>
<td>Mean Order Weight</td>
<td>3</td>
<td>100-1000</td>
<td>93.9%</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1300 lbs</td>
<td>-</td>
</tr>
<tr>
<td>Number of Consolidation Points</td>
<td>3</td>
<td>20-60</td>
<td>Negligible</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>10-70</td>
<td>6%</td>
</tr>
<tr>
<td>Holding Time</td>
<td>3</td>
<td>1-7</td>
<td>1.0%</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1-10</td>
<td>46%</td>
</tr>
</tbody>
</table>

Source: Masters, "The Effects of Freight Consolidation on Customer Service," p. 67, calculated from Jackson, An Experimental Investigation, Table 4-1, p. 149.
The holding costs are the penalty costs for delaying a shipment, either customer imposed or carrying costs. Costs of shipping the order are substituted for ordering costs in the economic order quantity formula. The rate of demand per unit time is used instead of annual demand. In the deterministic case, a cost/customer service tradeoff curve can be generated if the customer service measure is average units of time delay per hundredweight.

For the multi-period case, Brennan suggested a transformation of the Leontief substitution models from which the Wagner-Whitin inventory model was derived. By changing the meaning of the time parameters to study the inventory time periods remaining in a planner horizon, a model was developed to determine consolidation shipment size and timing.

In the stochastic demand case, Brennan considered dynamic programming situations under conditions where pre-shipping unordered product was either permitted or not permitted. He established upper and lower bounds for the optimal shipment quantity in the general case. Finally, he indicated that the consolidation process is similar to machine replacement problems in renewal theory.

Brennan made an important contribution to freight consolidation research by indicating existing management science techniques which may be applicable to consolidation decisions. In fact, he contended that each solution to an inventory problem has a corollary solution to a consolidation problem. Brennan's work to date has been strictly theoretical with no empirical investigation. The work is restricted to one product class and customer with consolidation over time only. He assumes constant shipment time and a fixed plus variable shipment cost function in most cases, which is applicable to private fleet situations. Brennan
has taken an important first step in applying inventory and renewal theory to practical consolidation problems.

Summary

The freight consolidation simulation studies generally used similar measures of system performance. The most common were 1) delivery time mean and variance and 2) a measure of cost. The differences in measurement of costs make comparison of results difficult. Ordering costs, transportation costs, and consolidation savings are not the same measures. However, the conclusions were consistent in that consolidation generally reduced costs except for the small number of orders and pooling points in the Jackson study. In both the Masters and Jackson studies, delivery time tended to increase and variance tended to stabilize with increased holding time except for the four days holding time noted by Jackson. Insensitivity to holding time in the Lai study is consistent with the low explained variance in the Masters study, although holding time was statistically significant in both the Masters and Jackson studies.

The Masters and Jackson studies used national consumer demand patterns and intermediate pooling points whereas Lai involved actual data to study a more restricted sample of shipments from a public warehouse direct to customers. These simulation studies considered consolidation across time and customers. Recent work by Brennan from a strictly theoretical standpoint suggests that inventory and renewal theory may be applicable to consolidation problems, although to date these techniques have been applied only to a single customer situation with consolidation across time only. Additional research seems warranted to assess the impact on the measures of system performances across different products and demand patterns.
Implications for the Present Research

The major conclusions drawn from reviewing the warehouse location and freight consolidation literatures are that 1) the two system structure strategies have not been compared directly, and 2) little work has been done in the area of freight consolidation. Considerable effort has been devoted to choosing optimal locations of warehouses without acknowledging that many of the approaches could also be used for selecting pooling points. Perhaps the failure to point out the similarities of warehouse and pooling point selections is indirect evidence that many researchers have not been aware of a need for such comparison. Yet a distribution system using pooling points is certainly an alternative to traditional remote stocking or direct shipment. Hence, a comparison appears to be needed.

The limited amount of work in freight consolidation suggests that additional studies may be useful, particularly in two areas: 1) expansion to multi-product, multi-plant situations, and 2) examination of industrial demand patterns. Previous research into freight consolidation has generally used one plant and one product or a limited geographic area, as in the Lai study. Masters used a national distribution and assumed demand distributed according to population. Whether these results are generalizable to other distributions of demand and multiple products is not clear. The methodology discussed in Chapter III is designed to address the research gaps identified.
CHAPTER III

RESEARCH METHODOLOGY

Overview

The review of the warehouse location and consolidation literatures indicates that warehouse location and consolidation strategies have not been compared. This chapter contains the research plan for such a comparison. First, the research questions posed in Chapter I are stated again as a basis for the discussion in the remainder of the chapter. Next, the research methodology to investigate those questions is defined. Finally, the plan for and results of the pilot study are discussed. The pilot study was used to ascertain whether the variables contributed sufficient explained variance to be retained in the research and to check on computer time and statistical power for possible revisions in sample size.

Research Questions and Hypotheses

In order to evaluate the relative benefits of different distribution structures, a broad range of demand and product characteristics was necessary for some estimate of the generalizability of the results. Given the wide range of variation in some of the independent variables, the six system structures under investigation were evaluated separately at each combination of demand and product characteristics levels to
avoid losing valuable results by averaging across variable levels. The results of these individual evaluations were then studied for possible relationships of the system structure, the demand, and the product characteristics to the distribution costs and service levels. This study structure is provided in Figure 3. To arrive at some conclusions about these relationships, answers to the following research questions are necessary.

1. What is the effect on distribution costs and delivery time of: a) pooling orders from plants, b) consolidating orders shipped from warehouses, c) shipping direct from warehouses, or d) shipping from plants?

2. Under what conditions is the use of pooling points preferable to warehouse distribution systems in terms of distribution costs and delivery time?

3. What demand, product, and system structure characteristics are most important in determining distribution costs?

Specific research hypotheses addressing question (1) are tested at the aggregate level over all the data and for each combination of demand and product characteristics levels under the assumption stated above that the system structures should be investigated at each level individually. An alpha value of .01 was selected to reduce the opportunity for type II errors because of the number of hypothesis tests to be performed.

1. **Distribution costs**

   \[ H_0: \text{There is no difference in total distribution costs among the system structures at alpha} = .01.\]
ALTERNATIVE SYSTEM STRUCTURE

NUMBER OF COMPUTER RUNS*

Shipped from Plants:

1. No Consolidation: 0 days holding time 96
2. Consolidation: 1 day holding time 96
3. Consolidation: 4 days holding time 96

Shipped from Warehouses:

4. No consolidation: 0 days holding time 96
5. Consolidation: 1 day holding time 96
6. Consolidation: 4 days holding time 96
Total 576

DEPENDENT VARIABLES**

INDEPENDENT VARIABLES

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution Cost/cwt</td>
<td></td>
</tr>
<tr>
<td>Mean Delivery Time</td>
<td></td>
</tr>
<tr>
<td>Delivery Time Variance</td>
<td></td>
</tr>
<tr>
<td>Annual Orders</td>
<td>2</td>
</tr>
<tr>
<td>Mean Order Size</td>
<td>2</td>
</tr>
<tr>
<td>Geographic Distribution of Demand</td>
<td>2</td>
</tr>
<tr>
<td>Plant Locations</td>
<td>3</td>
</tr>
<tr>
<td>Product Classes</td>
<td>4</td>
</tr>
</tbody>
</table>

*The number of computer runs equals the product of the levels of the independent variables = 2.2.2.3.4 = 96.

**All dependent variables are collected in each simulation run.

Figure 3. Study Structure.
1H₁: Direct, unconsolidated shipment from the plants is significantly more expensive than shipments using any other system structure investigated.

Both the warehouse location and consolidation literatures suggest that remote storage and pooling generally reduce costs because of economies of larger shipment rates. The first hypothesis can be restated to permit comparisons of direct shipment cost from plants with the costs of each alternative system individually. The specific subhypotheses are:

1Ha: Direct, unconsolidated shipments from plants are significantly more expensive than shipments from plants with a maximum holding time of one day.

1Hb: Direct, unconsolidated shipments from plants are significantly more expensive than shipments from plants with a maximum holding time of four days.

1Hc: Direct, unconsolidated shipments from plants are significantly more expensive than unconsolidated shipments from warehouses.

1Hd: Direct, unconsolidated shipments from plants are significantly more expensive than shipments from warehouses with a maximum holding time of one day.

1He: Direct, unconsolidated shipments from plants are significantly more expensive than shipments from warehouses with a maximum holding time of four days.

2. **Mean delivery time**

2H₀: There is no difference in mean delivery time among the system structures at alpha = .01.

2Ha: Mean delivery time for consolidated shipments from plants using a maximum holding time of one day is significantly greater than mean delivery time for direct shipments from plants.

2Hb: Mean delivery time for consolidated shipments from plants using a maximum holding time of four days is significantly greater than mean delivery time for direct shipment from plants.
2H<sub>c</sub>: Mean delivery time for consolidating shipments from warehouses using a maximum holding time of one day is significantly greater than mean delivery time for direct shipments from warehouses.

2H<sub>d</sub>: Mean delivery time for consolidated shipments from warehouses using a maximum holding time of four days is significantly greater than mean delivery time for direct shipments from warehouses.

Masters and Jackson found that at the aggregate level mean delivery time increased for consolidated shipments compared with unconsolidated shipments from a single source. Jackson noted lower delivery times for four days holding time and 50,000 orders per year.

3. Delivery time variance

3H<sub>0</sub>: There is no difference in delivery time variance among the system structures at alpha = .01.

3H<sub>a</sub>: Delivery time variance for consolidated shipments from plants using either a one day or a four day holding time is significantly greater than delivery time variance for all other distribution structures investigated.

Masters concluded that consolidation did not increase delivery time variance but Jackson noted some increases in variance with respect to direct shipment.

The above hypotheses were used to answer question (1) at each combination of demand and product characteristics. The answers to question (2) were obtained by aggregating the results of pairwise tests to determine either the lowest cost or shortest delivery time systems. The situations in which pooling was preferable to warehousing were different for an objective of low cost, shorter mean delivery time, or smaller delivery time variance.
Question (3) was investigated via discriminant functions and numerous ANOVA tables and coefficients from regression analyses. Those demand and product characteristics and levels which accounted for the most variance were assumed to be the most important of the levels studied in determining cost under the limitations of the current study.

The next sections consist of 1) defining dependent and independent variables and 2) indicating the stages of the research project including the model used for the simulations and statistical tests. An explanation of the pilot study and its results are included at the end of the section.

**Variables**

**Dependent Variables**

The dependent variables collected were distribution cost per hundred weight, mean delivery time, and delivery time variance for each distribution system structure for the different combinations of product and demand characteristics. Total system costs were needed since transportation costs would not compare the differences in costs of using warehouses with pooling. These differences are discussed in the model specification section and in Appendix F. A cost per hundred weight measure was used because shipment sizes varied across the alternative distribution systems studied. Delivery time mean and variance were used as measures of customer service level. Delivery time for an order was a gamma distributed random variable derived from distance traveled and order weight.

**Independent Variables**

The major variable under investigation is system structure. The structures investigated vary according to a) whether freight consolidation was used and b) whether warehouses were used. The consolidation -
no consolidation structures differed according to the number of days an order was held for accumulation with other orders before shipment. If the holding time was zero days, then no orders are consolidated. Consolidation was studied at two levels: one day holding time and four days holding time. Thus, the following possibilities exist: 1) shipped from plants - no consolidation, 2) shipped from plants with consolidation over one day or four days, 3) shipped from the warehouses - no consolidation, and 4) shipped from the warehouses with consolidation over one or four days. Freight consolidation of shipments from the plants involved the use of pooling points, whereas consolidation from warehouses did not.

Product and demand variables which appear to influence distribution costs and delivery times from previous research include total number of annual orders, order size, product class, plant locations, and the geographic distribution of demand.

Table 12 indicates the levels of the variables. The two levels of the number of annual orders were used in Masters' study. The 50,000 level was also used in Jackson's design. Each order size level represented the mean of a truncated normal distribution from which the weight for each order in the simulations was selected. Truncation was necessary to avoid shipment weights which were less than or equal to zero.

Two common industrial equipment shipment classes and a consumer goods class provided a range of shipment conditions. Class 100 was used for both the Masters and Jackson studies which investigated consumer goods shipments. Total demand was assumed to be equally divided across the product classes for multi-product distribution systems. Similarly, the total number of orders at each customer location was assumed to be
Table 12
Independent Variables and Variable Levels

<table>
<thead>
<tr>
<th>LEVELS</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Orders</td>
<td>50,000</td>
<td>250,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Order Size</td>
<td>500 lbs.</td>
<td>1500 lbs.</td>
<td></td>
<td>33% (60)</td>
</tr>
<tr>
<td>Product Class</td>
<td>60</td>
<td>77.5</td>
<td>100</td>
<td>33% (77.5)</td>
</tr>
<tr>
<td>Plant Locations*</td>
<td>East</td>
<td>Central</td>
<td>South</td>
<td>34% (100)</td>
</tr>
<tr>
<td></td>
<td>Central</td>
<td>South</td>
<td>East</td>
<td></td>
</tr>
<tr>
<td></td>
<td>South</td>
<td>East</td>
<td>Central</td>
<td></td>
</tr>
<tr>
<td>Geographic Demand Distribution</td>
<td>top 150 SMSA's by population</td>
<td>top 150 SMSA's by manufacturers' value added</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

System Structure Definitions:

- Holding Days: 0, 1, 4
- Use of Warehouses: Yes, No

*The specific locations of the plants are:

- East: Newark, New Jersey
- Central: Columbus, Ohio
- South: Dallas, Texas
equally divided among the product classes. Geographic distribution of demand was either proportional to the top 150 Standard Metropolitan Statistical Areas by population or by manufacturer's value added. House and Jamie suggest that one hundred fifty demand points are needed to reduce error in rate costs consistently below four percent.¹

The simulation model assumed that each product class was produced at a different plant to investigate the influence of different products produced in different locations. Three geographically different plant locations were selected for study. The combination of product class and plant locations in the research design resulted in each product being produced at each location at some point in this study.

The variables in Table 12 do not exhaust the list of variables potentially affecting distribution costs. However, the literature suggests the variables studied may influence at least those system structures using consolidation. Results of a pilot test were used to determine whether some of the variables should be dropped from the research project because of low explanatory power.

Steps in the Research Project

The research involved the following steps: 1) determine the best configurations for each of the system structures for each combination of product and demand characteristics, 2) simulate the system structures, 3) determine which structures provided the least cost for each product and demand combination, and 4) determine which factors were most important in

selecting the lowest cost system structure. These steps are diagrammed in Figure 4. The first step was basically a location analysis problem. Khumawala's branch and bound warehouse location algorithm was used to generate the configurations for both the warehousing and pooling point strategies. The researcher anticipated that only two configurations would be necessary for each combination of demand and product characteristic levels. The warehouse configuration would be used for both the warehouse-no consolidation and warehouse-consolidation structures under the assumption that no pooling points would be established between warehouses and customers. The pooling point configuration was used for orders consolidated over time from plants and no configuration was necessary for direct shipment from the plants.

Khumawala's algorithm had obtained optimal solutions for moderate-sized problems of 25 potential locations and 50 demand points and distribution costs in the hundreds of dollars. An optimal solution was not necessarily guaranteed in the present research since the problem considered 40 potential locations, 150 demand points and distribution costs in the millions of dollars. Thus, there could have been a possibility that differences across system structures were due to chance if no optimum were achieved. Results of a pilot study were used to investigate the need for more than two configurations per combination of demand and product levels and the need for conservative statistical tests in the MANOVA at step three to reduce the possibility of type I errors of claiming a difference exists when in fact no difference exists.

---

Figure 4. Diagram of the Study
$X = \text{demand and product combinations}$

Subscripts:

$n = \text{annual number of orders}$

$m = \text{mean order weight}$

$i = \text{product class/classes}$

$\lambda = \text{plant location}$

$g = \text{geographic distribution of demand}$

$S = \text{system structure}$

Subscripts:

$a = \text{consolidation used (Number of holding days} = 0,1,4)$

$b = \text{warehouse used} (0,1)$

Figure 4 (continued). Diagram of the Study
The second step was accomplished by the use of an event-oriented Monte Carlo simulation. For each system structure, one year defined as 250 days was simulated with orders randomly generated by customers according to the particular demand patterns and order sizes under investigation. Orders were generated separately for each product since each product was shipped from a different plant when warehouses were not used.

The plant locations were Newark, New Jersey, in the east, Columbus, Ohio, in the midwest, and Dallas, Texas, in the south. Demand was distributed as the 150 Standard Metropolitan Statistical Areas (SMSA's) with a) the highest population or b) the greatest manufacturer's value added served as the customer demand points. Not all the same SMSA's were used for demand distributed by population as for manufacturer's value added. Additionally, due to the level of aggregation of the freight rate tables used, the combination of some SMSA's resulted in 132 customer demand points for either demand distribution.

The probability of a customer generating an order or orders on a given day was a poisson random variable which was a function of the proportion of total annual demand for the customer and the proportion of total sales accounted for by the product under consideration. The order size was drawn from a normal distribution with means equal to 500 or 1500 pounds. The variance was equal to the mean to generate a wide range of shipment weights. Travel times were drawn from a gamma distribution which has been demonstrated to be representative of actual travel times
by DeHayes and Piercey. The formulas for calculating the gamma parameter were developed by Masters using regression and relying on the empirical data of Piercey.\textsuperscript{3}

The product investigated had a high value of $400 per hundredweight. Carrying costs were 30 percent of product value which resulted in $.33 per day assessed for product in storage or in transit. A low turnover rate of eight turns per year was assumed for products stored at the central warehouse or in remote storage. Freight costs were calculated from freight rates published for June, 1981. The specific model used for this research is presented in Appendix E and the logistics assumptions underlying the model are listed in Appendix F. The program listing appears in Appendix G.

The freight consolidation algorithm determined when orders were shipped and orders accumulated up to a specified number of days. If the total weight of orders for a specific pooling point did not meet the requirement for a full truckload by the time the oldest order had been held the maximum number of holding days, all orders for the pooling point were shipped as a consolidated shipment at the appropriate LTL weight category charge. In the case of consolidation from warehouses, orders were accumulated for shipment to a demand point rather than to a pooling point.

In step three, for each combination of product and demand characteristics a multivariate analysis of variance was performed across the distribution system structures. The objective of the MANOVA was to determine whether the overall costs per hundred weight or the delivery times and variances were statistically different. Post hoc comparisons were conducted using Duncan's multiple range test with alpha = .01 if the null hypothesis of no difference was rejected. An example is provided in figure 5.

More than one observation per cell is required to perform the MANOVA, so each annual run was divided into five batches of fifty days. Fisher's procedure for determining independence of batch means described in Pritsker and Pegden was used to test for independence of the observations.\(^4\) A pilot study was conducted to test whether the assumption of independence was reasonable for the conditions being investigated.

The fourth step involved discriminant analysis and three sets of regressions using the general linear model to assess which product, demand, and structure characteristics were most important in determining distribution costs.

The discriminant analysis tested for differences in mean vectors, and then classification analysis was used to predict which structure provided lowest cost by using the product and demand characteristics. The lowest cost observations were identified by Duncan's test. A service level constraint in average delivery time was imposed for managerial relevance. The structure selected was the lowest cost system meeting the service

Product and Demand Characteristics of Example Cell:

- 50,000 orders per year
- 500 pounds mean order size
- product class 70 (single product demand)
- top 150 SMSA's by population
- one plant located in Newark

Factors in MANOVA design:

<table>
<thead>
<tr>
<th></th>
<th>Number of Levels</th>
<th>Fixed or Random Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Structure</td>
<td>6</td>
<td>Fixed</td>
</tr>
<tr>
<td>Batches</td>
<td>5</td>
<td>Random</td>
</tr>
</tbody>
</table>

Dependent variables

- cost
- mean delivery time
- delivery time variance

Test $H_0$: no difference in dependent variables across structures.
If $H_0$ rejected, post hoc pairwise comparisons of the lowest cost structures using Duncan's test.

Figure 5. Example of MANOVA Application For One Product-Demand Combination
level constraint. All structures which were not significantly different from this structure and meeting the prescribed service level were also included. Thus, at least 96 observations were used in the analysis. The group variable was system structure, i.e., the six system structures under investigation. The independent variables were the five remaining factors from Table 12 which were represented by eight dummy variables.

The following regressions were performed with cost as the dependent variable with the five demand and product characteristics as independent variables:

1. Total sample for main and two-way interactions if the hypothesis that higher order interactions do not add significant explained variance was accepted.

2. Six regressions on the individual distribution structures defined by holding time and warehouse. Main effects and two-way interactions were used if the hypothesis stated above is accepted that higher order interactions do not provide significant explained variance.

3. The observations used in the discriminant analysis are also analyzed using regression.

The standardized coefficients from the above regressions were correlated via Kendall's tau statistic to indicate whether the factors had the same relative importance in determining costs across regressions.

The first two sets of regressions were also performed with delivery time and delivery time variance as dependent variables. The results were examined for differences in the relative explained variances of the independent variables across the dependent variables.
Before the regressions were performed the variables were checked for the need to include interaction terms or transformations. Previous consolidation research suggested that the interaction terms were small, generally contributed little to the explained variance and, thus, probably justified elimination. The importance of the interaction terms was tested using the hierarchical approach of the "extra sums of squares" principle suggested in Draper.\textsuperscript{5} The extra sums of squares accounted for by higher order interactions were tested against the full model error variance. Comparing the results of all the regressions yielded greater understanding of the interrelationships of system structure and the other independent variables regarding distribution costs.

The total sample size was 2880 observations, resulting from 576 combinations of levels of structure, product, and demand characteristics with five observations per cell. The smallest sample size of 480 for each system structure had sufficient power to detect an effect size of .10. The power was greater than .96 for this effect size.

Pilot Study Plan

A pilot study was conducted with the following objectives:

1. Determine if each variable contributed sufficient explained variance to be retained in the remainder of the research effort.

2. Assess whether sample size was large enough to detect the desired effect sizes.

3. Assess whether interactions among the variables were significant.

4. Investigate differences in location configurations.

The pilot study consisted of two fractional factorial designs to study consolidated and unconsolidated systems separately. The fractional factorial designs permitted estimates of all main effects and two-way interactions. The specific designs are contained in Conner and Young.6 With a knowledge of the confounding of the main effects and two-way interactions, the significance of the interactions can be tested. If the interactions are nonsignificant, then additional terms to account for interaction effects are not necessary in the regression model.

Power is a function of effect size and sample size.7 For regression analysis, effect size is a ratio of the mean square of the variables to the mean square error. Once effect size is estimated, the sample size can be determined to achieve a desired power to detect effects.

A further use of the pilot study was to determine whether configurations generated by Khumawala's algorithm were different across demand and product characteristics and system structures. Three configurations were generated for the pilot study. The configurations were examined to determine if they were different for warehouse locations where no consolidation strategy was used compared with warehouse locations using consolidation strategies. If these configurations did not differ greatly


in terms of cost and delivery time, the main study factorial design could be generated by using Khumawala's algorithm once for all warehouse structures for a particular demand and product combination. Second, all the results of the fractional factorial pilot study were reviewed to determine if configurations for a particular system structure vary across demand and product characteristics. The difference between levels of the variables was expected to be great enough to require separate location configurations to be generated for each combination of levels. If the configurations for the pooling strategy, for example, were the same across some levels of the variables, then intermediate cells not included in the pilot study could be assigned the location configuration of the adjacent cells. Such an occurrence would reduce the computer time to generate these configurations.

Results

The pilot study was able to provide useful information for each of the stated objectives. First, analysis of the pilot study data suggested that all independent variables should be retained for the entire study since the variables and many of the interactions were significant in both fractional factorial analyses.

The second objective was to determine whether the sample size of five observations per cell was large enough to detect desired differences in the dependent variables across levels of the independent variables. The largest within cell variance for the dependent variables in the pilot study was 1.08. The smallest differences in means occurred for delivery time. The power to detect a one day difference in delivery
time with a within cell variance of 1.08 was greater than .99. Thus, for the MANOVA analyses, power was certainly sufficient.

The third objective was to investigate whether interaction terms would have to be included in the regression analyses. Analysis of the pilot study data indicated that higher order interactions did not add significant explained variance. Since the model was altered between the pilot test and the main study, further analysis of which two-way interactions as well as whether any higher order interactions should be included is deferred until the entire study is completed.

The final objective of the pilot study was to assess whether each system structure required an individual configuration from the Khumawala location program. A study of the pilot test results indicated that different configurations resulted for system structures of warehouses with and without consolidation. Thus, a different configuration was constructed for these system structures in the main study.

Additional findings from the pilot study not directly related to the stated objectives are reported here for clearer explanation of the main study results contained in the next chapter. These findings include the nature of the generation of the random elements of the study and the definition of some of the fixed parameters of the study. Using a normal distribution with a mean equal to the levels in Table 12 resulted in the actual mean substantially higher than the stated mean because of truncation to avoid negative weights. To reduce the experimental mean to the 500 pound or 1500 pound levels required reducing the mean in the random generation function by twenty percent. While this technique achieved the desired mean order weight levels, the researcher studied other functions which achieve a wide variation in order weights to be more representative
of actual shipment distributions and still retain the overall mean of 500 or 1500 pounds. A trimodal function of normal random variables with means of 100, 500 or 1500 pounds, and 10,000 pounds was examined to create a wide range of order weights but the resulting overall mean was twice the anticipated mean. Various gamma and exponential function parameters were also examined but these also failed to achieve the desired overall mean and the desired spread in order weights. As a result of this investigation the truncated normal distribution with the reduced mean in the random generating function was chosen since it most closely paralleled the selections of previous researchers and the results of the current study would be more readily comparable with the previous studies. The researcher recognizes that this decision restricts the study to primarily small to medium sized shipments because the random generator will not yield larger order sizes. Such a study is left for future investigation.

One of the fixed parameters which does not have an established precedent in research is the restriction on pooling point volume. The nature of the Khumawala unconstrained program yielded solutions including virtually every potential pooling point because there was no variation in fixed costs across pooling points. The algorithm traded off variable costs against fixed costs. Since there were no fixed costs for pooling points, a minimum value was included for the program to run. With no difference in fixed costs, the algorithm included all potential locations. A restriction on minimum volume through the pooling points was necessary to preclude all possible locations from entering the final configuration. Three levels of pooling point volume were studied: 1000, 3000, and 5000
pounds from each plant per four day period. When separate pooling point configurations were generated for each plant, the simulations for the 5000 pound restriction yielded lower distribution costs and was selected for use in the main study. The Khumawala program was constrained to yield solutions where every pooling point achieved the minimum volume.

The Khumawala program was further constrained to yield warehouse configurations which included the plants. A solution which did not include plant warehouses was not considered compatible with most industrial situations. Results of the pilot study indicate that many initial solutions do not contain all the plants as warehouses. The results further indicate that this restriction does not completely bias the results in favor of pooling strategies since in more than one-half of the cells studied one of the warehouse solutions provided lower transportation costs than pooling directly from plants.

The Khumawala program had no difficulty solving the current problem sizes of 40 potential locations, 150 demand points, and costs potentially in the millions. However, the algorithm assigned a large number to demand-location pairs which were not to enter the solution, and in some cases the calculated costs exceeded this value. Therefore, two adjustments were made in the program: first, the large number was increased by two decimal places, and second, all costs were reduced by a factor of 100 for the costs for warehouse configurations. Since the warehouse configuration costs included storage and handling costs in addition to transportation costs, the figures were much higher for warehouse costs than for pooling costs.
Solutions generated by the Khumawala program were logical and no diagnostics were produced to indicate that a solution was not feasible except in certain cases where no demand occurred at a potential demand point because this researcher combined the demand locations for population and manufacturer's value added in one input file. Some demand locations for population were not among the top 150 value added locations and vice versa. Consequently, some locations would not have demand and therefore, did not have associated costs to input into the Khumawala program. The program was adjusted to prevent its stopping when zero volume demand point was encountered. This adjustment applied only at the beginning of the Khumawala program before the algorithm was executed.

Another use of the pilot test was to examine whether the batch means could be considered independent observations. Fishman's formula, discussed earlier, was calculated across the means of fifty-day batches in the cells. The hypothesis of no difference was accepted so the statistical procedures applied to the data which assume independence of observations were appropriate from this perspective.

A final note from the preliminary effort of model development and testing was the large amount of computer core storage required to run the complete model of location analysis and the simulations. The Amdahl 470 computer for the entire university community limited individual user space to 2048k. The model would not compile without the use of the INTEGER*2 mode in FORTRAN IV. Considerable time was devoted to debugging difficulties created from the necessity of using INTEGER*2 which assigns half-word space to integer values. All integer variables in the program used half-word storage unless specified as full word.
Even with the half-word mode, the model required almost 2048k. The Khumawala algorithm required more than 512k to compile and the remainder of the space was used for the simulation programs and supporting data matrices.

The pilot test proved quite valuable in assessing whether the methodology could be used for the problem under study, particularly since the fractional factorial designs included all levels of all factors. From the results of the pilot study, the data appear to have sufficient power for the analyses proposed. The results of the main study are reported in the next chapter.
CHAPTER IV

FINDINGS AND RESULTS

The results of the study are contained in this chapter. First, the data are examined to determine if they can support the proposed tests and analyses. Tests of the formal hypotheses are then presented, followed by a discussion of the discriminant and regression analyses. Additional findings of the research effort are also reported. Conclusions regarding the findings and results are deferred until Chapter Five.

Preliminary Examination of the Data

Before proceeding with the statistical tests of the hypotheses, the data were examined for their ability to support the analyses. Specifically, one should know whether the batch means were independent, whether higher order interactions needed to be examined, and whether the data had sufficient power to detect differences among group means and to detect explained variance. Each 250 day simulation was divided into fifty day batches to create five separate observations. Preliminary analysis reported in Chapter Three established that the five batches could be considered as independent observations for the statistical tests and analyses.
The second concern was whether to include higher order interactions in the analyses. The extra sums of squares test failed to reject the null hypothesis, suggesting that the three-way and higher order interactions were significant. The failure to reject the null hypothesis resulted from the extremely low mean squared error as indicated in Figure 6. A components of variance analysis indicated that the contribution of higher order interactions was less than .1 percent when cost was the dependent variable. This level was judged to be too low for further inclusion.

The third concern was whether there was sufficient power to detect the differences of interest in the dependent variables. The power of the tests remained reasonable when the entire set of data was considered. For the regression analyses, the lowest power to detect an effect size of .10 explained variance was greater than .99. At the .01 alpha level, a difference as small as 14 cents per hundredweight resulted in significantly different distribution costs across the system structures. Thus, the data appeared to justify the assumptions of independence of observations and provided sufficient power for the statistical tests.

**Hypothesis Tests**

The results of the multivariate analyses of variance and the Duncan's multiple comparisons tests from the Statistical Analysis System (SAS) which support the discussions of the hypothesis tests appear in Appendix H. The tables in this section are drawn from Appendix H.

**Hypothesis 1:** Direct, unconsolidated shipment from plants is significantly more expensive than shipment using any other structure.
Full Model: all seven independent variables and all possible interactions

**Sum of Squares:**

<table>
<thead>
<tr>
<th></th>
<th>Full Model</th>
<th>Reduced Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>23955.888</td>
<td>23546.361</td>
</tr>
<tr>
<td>Error</td>
<td>16.962</td>
<td>426.489</td>
</tr>
<tr>
<td>Total</td>
<td>23972.850</td>
<td>23972.850</td>
</tr>
</tbody>
</table>

**Mean Square:**

<table>
<thead>
<tr>
<th></th>
<th>Full Model</th>
<th>Reduced Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>41.662</td>
<td>386.005</td>
</tr>
<tr>
<td>Error</td>
<td>.007</td>
<td>6.151</td>
</tr>
</tbody>
</table>

\[ R^2 \equiv .999292 \quad .982209 \]

*Figure 6. Explained Variance for Full and Reduced Models with Cost as the Dependent Variable*

The null hypothesis that unconsolidated shipments from plants were not more expensive than shipments through any other distribution systems was rejected at the aggregate level and for forty-two combinations of demand and product characteristics listed in Table 13. As volume through the system increased, the null hypothesis was rejected more frequently. At the aggregate level, warehouse consolidation with either one or four days holding time was not significantly different from direct shipment from plants. All other system structures were significantly less expensive than direct shipment from plants. The hypothesis was postulated on results of previous research on freight consolidation which did not consider the use of warehouses.
Table 13

CELLS IN WHICH COST PER HUNDREDWEIGHT OF UNCONSOLIDATED SHIPMENTS FROM PLANTS WAS SIGNIFICANTLY GREATER THAN COST PER HUNDREDWEIGHT OF ALL OTHER STRUCTURES

($\alpha = .01$)

<table>
<thead>
<tr>
<th>Mean Order Weight</th>
<th>Total Annual Orders</th>
<th>Plant Location</th>
<th>Geographic Demand</th>
<th>Product Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>50000</td>
<td>South</td>
<td>Population</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>100</td>
</tr>
<tr>
<td>1500</td>
<td>50000</td>
<td>East</td>
<td>Population</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Central</td>
<td>Population</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South</td>
<td>Population</td>
<td>77.5, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>77.5, 100</td>
</tr>
<tr>
<td>500</td>
<td>250000</td>
<td>East</td>
<td>Population</td>
<td>77.5, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>77.5, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Central</td>
<td>Population</td>
<td>77.5, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>77.5, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South</td>
<td>Population</td>
<td>77.5, 100</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>77.5, 100</td>
</tr>
<tr>
<td>1500</td>
<td>250000</td>
<td>East</td>
<td>Population</td>
<td>A11, 77.5, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>A11, 77.5, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Central</td>
<td>Population</td>
<td>A11, 77.5, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>A11, 77.5, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South</td>
<td>Population</td>
<td>A11, 60, 77.5, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>A11, 60, 77.5, 100</td>
</tr>
</tbody>
</table>

42 (tests)
For greater understanding of the relative distribution costs of the different system structures, five subhypotheses which compared unconsolidated shipments from plants with each of the remaining alternatives were examined.

Hypothesis 1a: Direct, unconsolidated shipments from plants are significantly more expensive than shipments from plants with a maximum holding time of one day.

Hypothesis 1b: Direct, unconsolidated shipments from plants are significantly more expensive than shipments from plants with a maximum holding time of four days.

Hypothesis 1c: Direct, unconsolidated shipments from plants are significantly more expensive than unconsolidated shipments from warehouses.

Hypothesis 1d: Direct, unconsolidated shipments from plants are significantly more expensive than shipments from warehouses with a maximum holding time of one day.

Hypothesis 1e: Direct, unconsolidated shipments from plants are significantly more expensive than shipments from warehouses with a maximum holding time of four days.

The cases for which the null hypotheses of no difference were accepted are listed in Table 14. Direct, unconsolidated shipments from plants were not more expensive than consolidated shipments with a one day holding time in only thirteen cases. These instances occurred when all products were shipped and when 50,000 orders per year were shipped. The combination of these two factors resulted in the lowest volume of goods shipped for each product of approximately 16,000 orders. The smaller number of orders would result in orders being held for one day, but a
Table 14

Cells in which cost per hundredweight of unconsolidated shipments from plants was not more expensive than the alternative system cost per hundredweight

<table>
<thead>
<tr>
<th>Mean Order Weight</th>
<th>Total Annual Orders</th>
<th>Plant Location</th>
<th>Product Class</th>
<th>Geographic Demand (P=population, M=manufacturer's value added)</th>
<th>Violations of Hypothesis Test*</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 Lbs 50,000 East</td>
<td>A11</td>
<td>P,M</td>
<td>1Ha, 1Hc, 1Hd, 1He</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60,77.5</td>
<td>P,M</td>
<td>1Hc, 1Hd, 1He</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>P,M</td>
<td>1Hd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central</td>
<td>A11</td>
<td>P</td>
<td>1Ha, 1Hc, 1Hd, 1He</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A11</td>
<td>M</td>
<td>1Ha, 1Hc, 1Hd, 1He</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60,77.5</td>
<td>P,M</td>
<td>1Hc, 1Hd, 1He</td>
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</tr>
<tr>
<td></td>
<td>100</td>
<td>P</td>
<td>1Hd</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>M</td>
<td>1Hc, 1Hd, 1He</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>A11</td>
<td>P,M</td>
<td>1Ha, 1Hc, 1Hd, 1He</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>P,M</td>
<td>1Hc, 1Hd, 1He</td>
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</tr>
<tr>
<td></td>
<td>77.5</td>
<td>P,M</td>
<td>1Hd, 1He</td>
<td></td>
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</tr>
<tr>
<td>250,000 East</td>
<td>A11</td>
<td>P,M</td>
<td>1Ha, 1Hd, 1He</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>P,M</td>
<td>1Hc, 1Hd, 1He</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>60</td>
<td>P,M</td>
<td>1Hc, 1Hd, 1He</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central</td>
<td>A11</td>
<td>P,M</td>
<td>1Hc, 1Hd, 1He</td>
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<td></td>
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<tr>
<td></td>
<td>60</td>
<td>P,M</td>
<td>1Hc, 1Hd, 1He</td>
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<tr>
<td>1500 Lbs 50,000 East</td>
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<td>P,M</td>
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<td></td>
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<tr>
<td></td>
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<td>P,M</td>
<td>1Hc, 1Hd, 1He</td>
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<td></td>
<td>77.5</td>
<td>P,M</td>
<td>1Hd, 1He</td>
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<td>A11</td>
<td>P,M</td>
<td>1Ha, 1Hd, 1He</td>
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<td></td>
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<td>77.5</td>
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<td>1Hd, 1He</td>
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<tr>
<td></td>
<td>60</td>
<td>M</td>
<td>1Ha, 1Hc, 1Hd, 1He</td>
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<td>M</td>
<td>1Hc, 1Hd, 1He</td>
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<td>South</td>
<td>A11</td>
<td>P,M</td>
<td>1Hc, 1Hd, 1He</td>
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<tr>
<td></td>
<td>60</td>
<td>P,M</td>
<td>1Hc, 1Hd, 1He</td>
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</tr>
<tr>
<td></td>
<td>250,000 East</td>
<td>P,M</td>
<td>1He</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central</td>
<td>60</td>
<td>P,M</td>
<td>1Hd, 1He</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Hypotheses

1Ha: plant, unconsolidated cost > plant, 1 day holding time
1Hb: plant, unconsolidated cost > plant, 4 days holding time
1Hc: plant, unconsolidated cost > warehouse, unconsolidated
1Hd: plant, unconsolidated cost > warehouse, 1 day holding time
1He: plant, unconsolidated cost > warehouse, 4 days holding time
consolidated order apparently would not be of sufficient volume to save transportation costs over the costs of holding the order. In contrast, a strategy of holding orders up to four days for shipment from plants was always less expensive than direct shipment from plants. Even for the lower volume of 16,000 orders, holding orders up to four days resulted in lower distribution costs.

Most of the cases where direct, unconsolidated shipments from plants were not the most expensive means of distribution occurred for systems using warehouses. Direct shipment from warehouses was not less expensive in twenty-one cases and consolidation from warehouses was not less expensive in 48 and 46 cases for one and four day holding times, respectively. Direct shipments from warehouses were not less expensive than direct shipments from plants for lower volumes of orders and for lower product classes, particularly class 60. Direct shipments from plants were always more expensive for 250,000 orders and a mean order weight of 1500 pounds.

Consolidation strategies from warehouses were no less expensive than direct shipment from plants in half the cases. These cases were concentrated in volumes other than the largest total volume of 250,000 orders and 1500 pounds mean order weight. The cases were also concentrated in the shipment of products other than class 100 alone. Holding orders for shipment from warehouses appeared to dilute the value of consolidation with fewer orders available for consolidation to a single demand point. Consolidation strategies from warehouses were the main reasons for direct shipment from plants failing to be the most expensive method.
Hypothesis 2a: Mean delivery time for consolidated shipments from plants using a maximum holding time of one day is significantly greater than mean delivery time for direct shipments from plants.

The null hypothesis of no difference in delivery time was rejected over all the data with an alpha level of .0001. This rejection suggested that a one-day holding strategy significantly increased delivery time. One should note that a one day holding strategy as used in the present research could result in two extra days of delivery time. Orders could be shipped one day later than in a direct strategy and an additional day could be incurred for dividing the pooled shipment into individual orders at the pooling point.

When the ninety-six combinations of demand and product characteristic levels were examined individually, the hypothesis of no significant directional differences was accepted in twenty cases for alpha = .005. These cases are listed as 2Ha in Table 15. In all but two of the cases, all the product was shipped from one plant located in the east; with two exceptions the product is one of the two lower shipment classes: 60 or 77.5. The lower shipment classes were less expensive to ship per unit of weight and differences between freight rates by weight category were smaller than for the higher shipment class 100 rates. The lower product classes had fewer pooling points because of less incentive from differences in weight break categories to justify establishing additional pooling points. With more direct shipments, mean delivery time would be closer to the alternative where all product is shipped directly from plants.
Table 15

MEAN DELIVERY TIME FOR A CONSOLIDATION STRUCTURE IS NOT SIGNIFICANTLY GREATER THAN ASSOCIATED UNCONSOLIDATED STRUCTURE (α = .01)

<table>
<thead>
<tr>
<th>Plant Location</th>
<th>Product Class</th>
<th>Mean Order Weight</th>
<th>Total Annual Orders</th>
<th>Geographic Demand</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>60</td>
<td>500#</td>
<td>50,000</td>
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<td>250,000</td>
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<td>Mfrgr. Value+</td>
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<td>Population</td>
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<td>500#</td>
<td>250,000</td>
<td>Mfrgr. Value+</td>
<td>2 Ha</td>
</tr>
</tbody>
</table>

35 (tests)

2 Ha - 1 holding day vs. 0 holding days from plant.
2 Hb - 4 holding days vs. 0 holding days from plant.
2 Hc - 1 holding day vs. 0 holding days from warehouse.
2 Hd - 4 holding days vs. 0 holding days from warehouse.
Hypothesis 2b: Mean delivery time for consolidated shipments from plants using a maximum holding time of four days is significantly greater than mean delivery time for direct shipment from plants.

The null hypothesis that mean delivery time for shipments from plants using a four-day maximum holding time was not greater than delivery time for direct shipments from plants was rejected at the aggregate level with an alpha level of .0001. The null hypothesis was rejected for each combination of demand and product characteristics with three exceptions which involved product shipped from one east coast plant. The exceptions occurred only when volume and mean order weight were both at the highest levels as are listed as 2Hb in Table 15.

Hypothesis 2c: Mean delivery time for consolidated shipments from warehouses using a maximum holding time of one day is significantly greater than mean delivery time for direct shipments from warehouses.

The null hypothesis that mean delivery time for a one-day consolidation strategy was not greater than mean delivery time for direct shipment from warehouses was rejected at the aggregate level with alpha = .0001. The null hypothesis was accepted for eleven of the ninety-six combinations of demand and product characteristics. In each of the eleven cases the total annual volume was at the 250,000 order level, never at the 50,000 order level. These cases were listed as 2Hc in Table 15.

Hypothesis 2d: Mean delivery time for consolidated shipments from warehouses using a maximum holding time of four days is
significantly greater than mean delivery
time for direct shipments from warehouses.

The null hypothesis that mean delivery time for a four-day holding
strategy was no greater than direct shipment from warehouses was
rejected at the aggregate level and for all but one of the combinations
of demand and product characteristics.

Hypothesis 3: Delivery time variance for consolidated
shipments from plants using either a one
day or a four day holding time is signi-
ficantly greater than delivery time
variance for all other distribution
structures investigated.

The null hypothesis that delivery time variance for consolidated
shipments from plants was not greater than delivery time variance for
the other structures was accepted at the aggregate level. Across all
the data, delivery time variance for the four-day holding time for ship-
ments from plants was not significantly greater than delivery time vari-
ance for direct shipments from plants. Delivery time variance for both
zero and four days holding time from plants was significantly greater
than delivery time variance for the one-day holding time and all the
structures using warehouses. When the ninety-six combinations of
demand and product characteristics were examined, the null hypothesis
was accepted in all but fourteen cases. In nine of these cases, multi-
ple products were shipped at the 50,000 annual order level, as can be
seen in Table 16. This combination was the lowest volume shipped from
each plant in the study.
Table 16

<table>
<thead>
<tr>
<th>Mean Order Weight</th>
<th>Total Annual Orders</th>
<th>Plant Location</th>
<th>Geographic Demand</th>
<th>Both 1 and 4 Holding Days</th>
<th>4 Holding Days Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>500#</td>
<td>50,000</td>
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<td>Population</td>
<td>A11</td>
<td>A11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>A11</td>
<td>A11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Central</td>
<td>Population</td>
<td>A11</td>
<td>A11,60,77.5,100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>A11</td>
<td>A11,77.5,100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South</td>
<td>Population</td>
<td>A11, 77.5, 100</td>
<td>A11,60,77.5,100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mfgr. Value+</td>
<td>A11, 77.5</td>
<td>A11,60,77.5,100</td>
</tr>
<tr>
<td>500#</td>
<td>250,000</td>
<td>East</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>South</td>
<td>Population</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>1500#</td>
<td>50,000</td>
<td>East</td>
<td>Population</td>
<td>A11</td>
<td>A11</td>
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<td>Central</td>
<td>Population</td>
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<td>A11</td>
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</tr>
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<td>Population</td>
<td>A11,60,77.5</td>
<td>A11,60</td>
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<td>Population</td>
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<td>100</td>
</tr>
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<td>Population</td>
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<td>A11</td>
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<td>Mfgr. Value+</td>
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</table>

14 cases (tests)    32 cases (tests)
Discriminant and Regression Findings

**Discriminant Analysis**

The purpose of the discriminant and associated classification analyses was to investigate whether the variables in the study could be used to predict lowest cost structure or structures. The lowest cost structure which provided a mean delivery time of six days or less was selected from each of the ninety-six combinations of demand and product characteristics for use in the discriminant analysis. Any additional system structure not significantly more expensive in dollars per hundredweight than the lowest cost structure and meeting the service level constraint of six days was included in the discriminant analysis. A conservative alpha level of .01 was used in the selection of the lowest cost system using analysis of variance.

A total of 112 system structures were selected. Since each structure had five observations, 560 observations were used in the discriminant analysis. The 560 observations were necessary because one system structure accounted for only eight of the 112 observations. Eight observations for one group was considered too small for use in the discriminant analysis because there would be as many variables as observations for that group. By using 560 observations, the smallest group contained forty observations which exceeded the eight variables used in the analysis. The structures included in the discriminant analysis are shown in Table 17 for each combination of demand and product characteristics.

The variables used to construct the discriminant functions were annual volume, mean order weight, geographic distribution of demand,
Table 17
LOWEST COST STRUCTURES SUBJECT TO MEAN DELIVERY TIME OF LESS THAN 6 DAYS

<table>
<thead>
<tr>
<th>Product Class</th>
<th>Geographic Demand</th>
<th>Mean Order Weight</th>
<th>Total Annual Orders</th>
<th>Plant Location</th>
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<td>Central</td>
</tr>
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<td>4</td>
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<tr>
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<td>3</td>
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</tr>
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</tr>
<tr>
<td></td>
<td></td>
<td>250,000</td>
<td>6</td>
<td>3,6,2</td>
</tr>
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</table>

1 - plant, 0 holding days
2 - plant, 1 holding day
3 - plant, 4 holding days
4 - warehouse, 0 holding days
5 - warehouse, 1 holding day
6 - warehouse, 4 holding days
plant location, and product classes shipped. Volume and weight were continuous variables. The remaining variables were categorical and, therefore, were represented as dummy variables. A total of eight variables were used in the discriminant analysis as indicated in Figure 7.

The group variable was system structure. The number of observations for each structure is listed in Figure 8. Group five, one day holding time from warehouses, had no observations and was omitted from the discriminant analysis. Since the sizes of the remaining groups were quite different, the PRIORS = SIZE option in SPSS was used instead of assuming all groups to be equal.

All eight variables were significant at alpha = .03 and seven were significant at alpha = .0001. Thus, each variable entered the stepwise solution. The smallest "f to enter" was 2.67 for product class 77.5, represented as PROD2. Of the four possible discriminant functions, two explained 94.8 percent of the variance. The two functions were rotated although the rotated and unrotated functions had very similar canonical correlations with the discriminant variables. The correlations of the rotated functions with the discriminant variables and the group centroids are listed in Table 18.

The first function suggested an influence of the dispersion of plant location and demand on the choice of distribution system. The function accounted for 56.09 percent of the explained variance. The dummy variable for geographic distribution of demand and the two dummy variables used to represent the three plant locations were the most important variables for the first discriminant function. Examination of the group centroids for the first function indicated that all structures which shipped only from plants had negative centroid values while
Continuous Variables

Volume (50 days)                        VOL
Mean Order Weight                      MOW

Categorical Variables       Levels       Number of Dummy Variables
Product Class               60
                                3
                                77.5
                                100
                                All (60,
                                77.5,100)
                                PROD1
                                PROD2
                                PROD3

Geographic Distribution of Demand
by Population
by Manufacturer's Value Added

Plant Location
East (Newark) 2
Central(Columbus)
South(Dallas)

8 variables

Figure 7. Variables used in Discriminant Analysis
<table>
<thead>
<tr>
<th>Group</th>
<th>Size</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>direct shipment from plant; 0 holding days</td>
</tr>
<tr>
<td>2</td>
<td>95</td>
<td>consolidation from plant; 1 holding day</td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td>consolidation from plant; 4 holding days</td>
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<tr>
<td>4</td>
<td>290</td>
<td>direct shipment from warehouse; 0 holding days</td>
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<tr>
<td>5</td>
<td>0</td>
<td>consolidation from warehouse; 1 holding day</td>
</tr>
<tr>
<td>6</td>
<td>90</td>
<td>consolidation from warehouse; 4 holding days</td>
</tr>
</tbody>
</table>

Figure 8. Discriminant groups.
### Table 18

**DISCRIMINANT FUNCTIONS**

**Correlations of Rotated Functions and Discriminant Variables**

<table>
<thead>
<tr>
<th></th>
<th>Function 1</th>
<th>Function 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 0</td>
<td>-0.43216</td>
<td>0.07774</td>
</tr>
<tr>
<td>GEOG</td>
<td>0.40866</td>
<td>0.05860</td>
</tr>
<tr>
<td>P1 1</td>
<td>0.39807</td>
<td>-0.14829</td>
</tr>
<tr>
<td>PROD 1</td>
<td>-0.31528</td>
<td>-0.18883</td>
</tr>
<tr>
<td>PROD 2</td>
<td>-0.10924</td>
<td>-0.00291</td>
</tr>
<tr>
<td>PROD 3</td>
<td>0.18619</td>
<td>0.60509</td>
</tr>
<tr>
<td>VOL</td>
<td>-0.01085</td>
<td>0.45785</td>
</tr>
<tr>
<td>WT</td>
<td>-0.06464</td>
<td>0.14620</td>
</tr>
</tbody>
</table>

**Definition of dummy variables:**

- **Geog:** 0 = manufacturers' value added
  1 = population

- **Plants:**
  0 0 = plant in East (Newark)
  1 0 = plant in Midwest (Columbus)
  0 1 = plant in South (Dallas)

- **Products:**
  Prod 1  Prod 2  Prod 3
  0 0 0 = all products in model
  1 0 0 = product class 60
  0 1 0 = product class 77.5
  0 0 1 = product class 100

**Group Centroids**

<table>
<thead>
<tr>
<th>Group</th>
<th>Function 1</th>
<th>Function 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.26256</td>
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<td>2</td>
<td>-1.44460</td>
<td>0.20405</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>4</td>
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</tr>
<tr>
<td>5</td>
<td>0.43892</td>
<td>1.82212</td>
</tr>
</tbody>
</table>
the two systems which shipped from warehouses had positive values. Closer examination indicated that the alignment of the group centroid values for the first function followed the same pattern as the order of mean delivery times for the entire data set. Direct shipment from warehouses had the shortest mean delivery time. The longest delivery time across the entire data set was for four days holding time from plants. The rank order of structures by mean delivery time was four, one, and zero holding days from warehouses. (Refer to the discussion of Hypotheses 2a-d and Appendix H.) Thus, the farther a plant and its demand are separated, the more likely warehouses will be needed to meet a customer service requirement of six days delivery time.

The second discriminant function suggested that the more class 100 product shipped, the more likely that pooling should occur. For product class 100, the most expensive class to ship of those studied, the number of orders correlated most highly with the second function. Those structures which did not use pooling, groups one and four, had negative group centroid values while those alternatives using pooling had positive values. The most negative value was for direct shipments from plants; the most positive value was for four days holding time from warehouses. The second function accounted for 38.71 percent of variance.

A comparison of the group centroid values for function one and function two suggested that whether warehouses were used was more important for the first function. Whether or not pooling was used was more important for the section function. The group centroid values for function one were rank ordered from plant-four days holding time,
plant-one day holding time, to warehouse-zero holding time. The group centroid values for function two were rank ordered from zero holding time from plants, zero holding time from warehouses to four day holding time from warehouses as shown in Table 18 on page 96.

The test for equality of group covariance matrices could not be made since all but one of the groups were singular. An examination of the dummy variables used in the discriminant analysis indicated that some of the variables had only one value for particular groups. As indicated in Figure 9, direct shipment from plants was never selected if class 100 was the only product shipped. Class 100 was the most expensive shipment class and had the greatest differences in cost per hundredweight between weight breaks in the rates. Thus, if larger shipments occurred through consolidation of orders or truckload shipments to warehouses, direct shipment would be less likely to provide the lowest cost method of distributing the product.

Group three, four-day consolidation from plants, was the lowest cost alternative only when demand was distributed as manufacturers' value added. Since demand was more concentrated for manufacturers' value added than for population, consolidated shipments would be larger and possibly be shipped more frequently. Shipment cost per hundredweight would be reduced and lower holding costs would be incurred if shipment occurred before the four day limit.

Groups two and three, consolidation from plants, were not the lowest cost structures when the plant was in Dallas. Since Dallas was located farther from the concentrations of either population or manufacturers' value added, warehouses were needed to have mean delivery times of less than six days.
<table>
<thead>
<tr>
<th>GROUP VARIABLE: STRUCTURE</th>
<th>CLASSIFICATION VARIABLES AND LEVEL WHICH CONTAINS ALL OBSERVATIONS FOR GROUP INDICATED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geog.</td>
</tr>
<tr>
<td>Plant - 0 holding days</td>
<td>0</td>
</tr>
<tr>
<td>Plant - 1 holding day</td>
<td>0</td>
</tr>
<tr>
<td>Plant - 4 holding days</td>
<td>0</td>
</tr>
<tr>
<td>Warehouse - 0 holding days</td>
<td></td>
</tr>
<tr>
<td>Warehouse - 4 holding days</td>
<td></td>
</tr>
</tbody>
</table>

Geog: 0 = manufacturer's value added  
1 = population  

Pl 1 = 0  Dallas never plant  
Prod 1 = 0  Never class 60  
Prod 3 = 0  Never class 100  

Figure 9. Singularity of Discriminant Variables with Group Variable
The classification table provided by SPSS, Statistical Package for the Social Sciences, indicated that 73.00 percent of the cases would be correctly classified. (See Table 19). Three of the groups had most of their cases correctly classified, but in group one, 75 percent of its cases were misclassified as group four and in group three, 69 percent of its cases were classified as group two.

As an additional assessment of the discriminant functions, real data from three plants were analyzed. Multiple product classes could be produced at each of the plants and the order weights were not necessarily normally distributed. Calculations using the unstandardized discriminant coefficients predicted group three as the lowest cost structure, subject to a six day delivery time. The next closest group centroids were for groups two and six. The lowest cost system using Duncan's multiple range test from the real data simulations was group three, but it was not statistically different from groups one or two at alpha = .01. These results were encouraging but were certainly not conclusive to determine the value of the classification functions for predicting group membership.

Regression Analyses

Seven separate regression analyses were performed with cost per hundredweight and mean delivery time each as the dependent variable. The seven analyses consisted of each of the six system structures and the total data set. The lowest cost structures used in the discriminant analysis were also regressed on cost. Only the main effects and two way interactions were included in the models. Since six of the
Table 19

**LEAST COST STRUCTURES**

**CLASSIFICATION RESULTS**

<table>
<thead>
<tr>
<th>ACTUAL GROUP</th>
<th>NO. OF CASES</th>
<th>PREDICTED GROUP MEMBERSHIP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>GROUP 0</td>
<td>40</td>
<td>6</td>
</tr>
<tr>
<td>GROUP 1</td>
<td>95</td>
<td>0</td>
</tr>
<tr>
<td>GROUP 2</td>
<td>45</td>
<td>0</td>
</tr>
<tr>
<td>GROUP 3</td>
<td>290</td>
<td>5</td>
</tr>
<tr>
<td>GROUP 5</td>
<td>90</td>
<td>0</td>
</tr>
</tbody>
</table>

**PERCENT OF "GROUPED" CASES CORRECTLY CLASSIFIED: 73.21%**

**CLASSIFICATION PROCESSING SUMMARY**

- 560 CASES WERE PROCESSED.
- 0 CASES WERE EXCLUDED FOR MISSING OR CUT-OF-RANGE GROUP CODES.
- 0 CASES HAD AT LEAST ONE MISSING DISCRIMINATING VARIABLE.
- 560 CASES WERE USED FOR PRINTED OUTPUT.
regressions were by system structure, the two variables used in defining structure, holding time and use of warehouses, were not included in these regressions.

Cost as the Dependent Variable

The most important factor across the entire data set was mean order weight which accounted for 42.1 percent of the variance in Table 20. The ANOVA tables and the beta coefficients for each regression are contained in Appendix I. Product class was the second most important predictor at 29.6 percent, followed by total annual orders at 6.8 percent and plant location at 3.5 percent of the variation. Geographic distribution of demand had the lowest explanatory power at 1.9 percent. The four significant two-way interactions at alpha = .0001 are graphed in Figures 10 through 13, although their explained variance was quite low. Three of the interactions involved the product class variable: products by mean order weight, products by geographic distribution of demand, and products by plant location.

In the first interaction, as mean order weight increased, differences in cost per hundredweight across product classes decreased slightly. In the second interaction, costs per hundredweight were less for demand distributed as manufacturer's value added than for demand distributed as population. Again a slight convergence of cost across product classes occurred as did mean order weight.

The products by plant interaction was the only one with more than one percent of the explained variance and was significant because of the almost stable cost for the multiproduct case across plant location. In each of the single product instances, costs decreased when shipped
Table 20
EXPLAINED VARIANCE OF MAIN EFFECTS AND TWO-WAY INTERACTIONS FOR SEVEN VARIABLES MODEL
(Dependent variable: Cost)

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of Freedom</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Annual Orders (TAO)</td>
<td>1</td>
<td>6.8</td>
</tr>
<tr>
<td>Mean Order Weight (MOW)</td>
<td>1</td>
<td>42.5</td>
</tr>
<tr>
<td>Product Class (PRODS)</td>
<td>3</td>
<td>29.6</td>
</tr>
<tr>
<td>Geographic Distribution of demand (GEOG)</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>Plant Location (PLANT)</td>
<td>2</td>
<td>3.5</td>
</tr>
<tr>
<td>Use of Warehouses (WHSE)</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>Maximum Holding Time (MHT)</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>TAO * MOW</td>
<td>1</td>
<td>.6</td>
</tr>
<tr>
<td>TAO * PRODS</td>
<td>3</td>
<td>.6</td>
</tr>
<tr>
<td>TAO * GEOG</td>
<td>1</td>
<td>.4</td>
</tr>
<tr>
<td>TAO * PLANT</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>TAO * WHSE</td>
<td>1</td>
<td>.4</td>
</tr>
<tr>
<td>TAO * MHT</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>MOW * PRODS</td>
<td>3</td>
<td>.5</td>
</tr>
<tr>
<td>MOW * GEOG</td>
<td>1</td>
<td>.8</td>
</tr>
<tr>
<td>MOW * PLANT</td>
<td>2</td>
<td>.8</td>
</tr>
<tr>
<td>MOW * WHSE</td>
<td>1</td>
<td>.8</td>
</tr>
<tr>
<td>MOW * MHT</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>PRODS * GEOG</td>
<td>3</td>
<td>1.4</td>
</tr>
<tr>
<td>PRODS * PLANT</td>
<td>6</td>
<td>1.4</td>
</tr>
<tr>
<td>PRODS * WHSE</td>
<td>3</td>
<td>.1</td>
</tr>
<tr>
<td>PRODS * MHT</td>
<td>6</td>
<td>.1</td>
</tr>
<tr>
<td>GEOG * PLANT</td>
<td>2</td>
<td>.3</td>
</tr>
<tr>
<td>GEOG * WHSE</td>
<td>1</td>
<td>1.6</td>
</tr>
<tr>
<td>GEOG * MHT</td>
<td>2</td>
<td>1.6</td>
</tr>
<tr>
<td>PLANT * WHSE</td>
<td>2</td>
<td>.3</td>
</tr>
<tr>
<td>PLANT * MHT</td>
<td>4</td>
<td>.3</td>
</tr>
<tr>
<td>WHSE * MHT</td>
<td>2</td>
<td>4.6</td>
</tr>
<tr>
<td>Error</td>
<td>2879</td>
<td>1.8</td>
</tr>
</tbody>
</table>
Figure 10. Two Way Interaction: Annual Orders and Products
Tao    Prods
Figure 11. Two Way Interaction: Mean Order Weight and Products 
MOW
PRODS
Figure 12. Two Way Interaction: Products and Plant Locations
Figure 13. Two Way Interaction: Plant Locations and Geographic Distribution of Demand
from the Columbus plant, but for the multiproduct case no decrease occurred. In the multiproduct case three plants each shipped a different product class, though the product class shipped from a specific plant varied.

The plant location listed indicated which plant shipped class 60. The other two classes were each shipped from one of the other two plants. Across the three plant locations listed, each product was shipped from each plant location once. The stability of the costs across these combinations of product class and plant location indicated that the different product-plant combinations did not affect costs when all three plants shipped products with equal demands. The last interaction was between plant location and geographic distribution of demand. The difference in cost for the two demand patterns was much smaller when the plant was located in Dallas than when it was located in either Newark or Columbus.

Comparisons across the eight regression model weights indicated that all system structures were significantly correlated according to Kendall's Tau (See Table 21). In fact, all regressions except for direct shipment from plants had correlation coefficients of .7 or higher with each other. The explained variances of the main effects and two-way interactions for each regression appear in Table 22. An examination of that table indicates that structure one, direct shipments from plants, differed from the other structures in one major respect. Total annual orders contributed no explained variance, whereas this variable accounted for at least six percent of the variance for the other structures. Since orders were shipped individually, varying
### Table 21

**STATISTICAL ANALYSIS SYSTEM**

<table>
<thead>
<tr>
<th>Group</th>
<th>S0</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>TOT</th>
<th>DIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant-0 da</td>
<td>1.000000</td>
<td>0.65530</td>
<td>0.60227</td>
<td>0.72727</td>
<td>0.54924</td>
<td>0.57576</td>
<td>0.74262</td>
<td>0.48864</td>
</tr>
<tr>
<td>Plant-1 da</td>
<td>0.65530</td>
<td>1.000000</td>
<td>0.77273</td>
<td>0.76136</td>
<td>0.72727</td>
<td>0.71591</td>
<td>0.83712</td>
<td>0.70455</td>
</tr>
<tr>
<td>Plant-4 da</td>
<td>0.60227</td>
<td>0.77273</td>
<td>1.000000</td>
<td>0.76894</td>
<td>0.81061</td>
<td>0.80682</td>
<td>0.82955</td>
<td>0.78030</td>
</tr>
<tr>
<td>Warehouse-0 da</td>
<td>0.72727</td>
<td>0.76136</td>
<td>0.76894</td>
<td>1.000000</td>
<td>0.79167</td>
<td>0.80303</td>
<td>0.87121</td>
<td>0.70833</td>
</tr>
<tr>
<td>Warehouse-1 da</td>
<td>0.54924</td>
<td>0.72727</td>
<td>0.81061</td>
<td>0.79167</td>
<td>1.000000</td>
<td>0.92803</td>
<td>0.80682</td>
<td>0.79545</td>
</tr>
<tr>
<td>Warehouse-4 da</td>
<td>0.57576</td>
<td>0.71591</td>
<td>0.80682</td>
<td>0.80303</td>
<td>0.92803</td>
<td>1.000000</td>
<td>0.81818</td>
<td>0.75379</td>
</tr>
<tr>
<td>All data</td>
<td>0.74242</td>
<td>0.83712</td>
<td>0.82955</td>
<td>0.87121</td>
<td>0.80682</td>
<td>0.81818</td>
<td>1.000000</td>
<td>0.71591</td>
</tr>
<tr>
<td>Discriminant</td>
<td>0.48864</td>
<td>0.70455</td>
<td>0.78030</td>
<td>0.78833</td>
<td>0.79545</td>
<td>0.75379</td>
<td>0.71591</td>
<td>1.000000</td>
</tr>
</tbody>
</table>
Table 22

EXPLAINED VARIANCE OF MAIN EFFECTS AND TWO-WAY STRUCTURES FOR SIX SYSTEM STRUCTURES AND FOR DISCRIMINANT ANALYSIS DATA

(Independent Variable: Cost)

<table>
<thead>
<tr>
<th>Source</th>
<th>Structures</th>
<th>Discriminant Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total Annual Orders (TAO)</strong></td>
<td>10.7%</td>
<td>11.4%</td>
</tr>
<tr>
<td><strong>Mean Order Weight (MOW)</strong></td>
<td>28.7%</td>
<td>27.0</td>
</tr>
<tr>
<td><strong>Product Class (PRODS)</strong></td>
<td>58.2%</td>
<td>39.9</td>
</tr>
<tr>
<td><strong>Geographic Distribution of Demand (GEOG)</strong></td>
<td>1.2</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>Plant Location (PLANT)</strong></td>
<td>6.7</td>
<td>4.1</td>
</tr>
<tr>
<td>TAO * MOW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAO * PRODS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAO * GEOG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOW * PRODS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOW * GEOG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOW * PLANT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRODS * GEOG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRODS * PLANT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GEOG * PLANT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Values less than 1. percent are omitted from the table with the exception of the error time.

1 = plant - 0 days holding time
2 = plant - 1 day holding time
3 = plant - 4 days holding time
4 = warehouse - 0 days holding time
5 = warehouse - 1 day holding time
6 = warehouse - 4 days holding time
the total number of orders shipped would not affect the average cost per hundredweight.

A second difference from three of the other structures was that mean order weight did not account for the most variance for direct shipments from plants. A one day holding time for shipments from plants and four days holding time from warehouses were the only other structures for which mean order weight was not the most important variable. Product class was more important in these structures. For the two structures mentioned which shipped only from plants, the differences in weight breaks for the three classes of product studied may have resulted in greater differences in shipment costs than larger shipments incurred under the other structures for at least a portion of the distance. In the case of four days holding time from warehouses, shipping all three products from a warehouse would reduce by one third the potential for consolidating orders by shipment class. If orders had to be held up to the four day limit before shipment, then holding costs would increase.

Mean order weight and product class were the two most important variables for all structures except four days holding time from warehouses. For that structure, the number of total annual orders was more important than product class. A larger number of annual orders would increase the probability of receiving enough orders to schedule larger, less expensive shipments. While larger numbers of orders would also be advantageous for other consolidation structures, receiving few orders for shipment to specific demand points would result in orders held four days before shipment which would increase holding costs more than for the other structures. Plant location and geographic distribution of demand explained between one and seven percent of the variance across
the structures. The two-way and higher order interactions were negligible in determining distribution costs in this study.

**Mean Delivery Time as the Dependent Variable**

The algorithm for generating the delivery time of an order was a function of distance travelled and shipment weight. The longer the distance, the longer the delivery time. Also, the larger the shipment weight, the shorter the delivery time, especially for full truckloads. The location of the plants, the geographic distribution of demand, and the interaction of plant location with product class were the most important factors in determining delivery time for shipment from plants, as may be seen in Table 23.

For shipments from warehouses the total number of annual orders, mean order weight, and product class appeared to influence delivery time. The mean order weight, of course, affected the weight of specific shipments. Total annual orders and product class do not directly affect distance or weight, however. The importance of these variables may result from a) the manner in which the warehouse configurations were generated and b) the lack of importance of plant location, given that shipments were from warehouses. Different warehouse configurations were created for each combination of demand and product characteristics, as shown in Table 24. The data used to generate these configurations varied according to the possible combinations. Larger numbers of orders, for example, would support more warehouses located closer to the markets and, thus, provide shorter delivery times.

Whether or not warehouses were used was the most important variable across the entire data set. The main effect and interactions involving
Table 23

EXPLAINED VARIANCE OF MAIN EFFECTS AND TWO-WAY INTERACTIONS FOR SIX SYSTEM STRUCTURES
(Independent variable: Delivery Time)

<table>
<thead>
<tr>
<th>Source</th>
<th>Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Total Annual Orders (TAO)</td>
<td>.6</td>
</tr>
<tr>
<td>Mean Order Weight (MOW)</td>
<td>4.8</td>
</tr>
<tr>
<td>Product Class (PRODS)</td>
<td>7.0</td>
</tr>
<tr>
<td>Geographic Distribution of Demand (GEOG)</td>
<td>16.2</td>
</tr>
<tr>
<td>Plant Location (PLANT)</td>
<td>56.4</td>
</tr>
<tr>
<td>TAO * MOW</td>
<td>.6</td>
</tr>
<tr>
<td>TAO * PRODS</td>
<td>2.9</td>
</tr>
<tr>
<td>TAO * GEOG</td>
<td>1.0</td>
</tr>
<tr>
<td>MOW * PRODS</td>
<td>.3</td>
</tr>
<tr>
<td>MOW * GEOG</td>
<td>.3</td>
</tr>
<tr>
<td>MOW * PLANT</td>
<td>.3</td>
</tr>
<tr>
<td>PRODS * GEOG</td>
<td>.1</td>
</tr>
<tr>
<td>PRODS * PLANT</td>
<td>18.5</td>
</tr>
<tr>
<td>GEOG * PLANT</td>
<td>2.5</td>
</tr>
<tr>
<td>Error</td>
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</tr>
<tr>
<td>Product Class</td>
<td>Geog. Distr.</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
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<tr>
<td></td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>M</td>
</tr>
</tbody>
</table>

*P = polulation  
M = Manufacturers' Value Added  
** PP = pooling from plants only (either 1 or 4 days holding time)  
W = no pooling from warehouses  
WP = pooling from warehouses (either 1 or 4 days holding time)
the WHSE variable accounted for more than 60 percent of the variance, as illustrated in Table 25. The total number of annual orders and the number of days an order could be held each accounted for approximately ten percent of the variance. Both of these variables would be important if a consolidation strategy is considered. The results of the analysis using all the data indicated that both the use of warehouses and/or consolidation strategies have a substantial influence in mean delivery time.

Additional Findings

Analysis of Real Data

In order to study data from a major corporation, the simulation programs were modified to accommodate shipping multiple products from one plant. The number of plants and the number of products were each restricted to three to conform with the limitations of the programs. The plants were chosen to give some geographic representation and provide a range of shipment volumes. The plants were located in the Midwest and Midsouth. The product classes studied were limited to those with the highest volume of shipments and were concentrated between shipment classes 60 and 77.5. Product classes having volumes too low to support pooling as suggested by Jackson were omitted. The demand pattern was not distributed as population or manufacturer's value added but was more concentrated in fewer markets.

The research hypotheses tested on the real data had results similar to those of the hypothetical data. The lowest cost distribution systems not statistically different from each other used plants with
<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of Freedom</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Annual Orders (TAO)</td>
<td>1</td>
<td>9.3%</td>
</tr>
<tr>
<td>Mean Order Weight (MOW)</td>
<td>1</td>
<td>4.9</td>
</tr>
<tr>
<td>Product Class (PRODS)</td>
<td>3</td>
<td>2.4</td>
</tr>
<tr>
<td>Geographic Distribution of demand (GEOG)</td>
<td>1</td>
<td>2.4</td>
</tr>
<tr>
<td>Plant Location (PLANT)</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>Use of Warehouses (WHSE)</td>
<td>1</td>
<td>46.4</td>
</tr>
<tr>
<td>Maximum Holding Time (MHT)</td>
<td>2</td>
<td>10.7</td>
</tr>
<tr>
<td>TAO * MOW</td>
<td>1</td>
<td>.2</td>
</tr>
<tr>
<td>TAO * PRODS</td>
<td>3</td>
<td>.2</td>
</tr>
<tr>
<td>TAO * GEOG</td>
<td>1</td>
<td>.2</td>
</tr>
<tr>
<td>TAO * PLANT</td>
<td>2</td>
<td>.2</td>
</tr>
<tr>
<td>TAO * WHSE</td>
<td>1</td>
<td>.2</td>
</tr>
<tr>
<td>TAO * MHT</td>
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<td>.2</td>
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<tr>
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<td>.7</td>
</tr>
<tr>
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<td>3.4</td>
</tr>
<tr>
<td>PRODS * PLANT</td>
<td>6</td>
<td>3.4</td>
</tr>
<tr>
<td>PRODS * WHSE</td>
<td>3</td>
<td>4.7</td>
</tr>
<tr>
<td>PRODS * MHT</td>
<td>6</td>
<td>4.7</td>
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<td>4.7</td>
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<td>4.7</td>
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<td>GEOG * MHT</td>
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<td>4.7</td>
</tr>
<tr>
<td>PLANT * WHSE</td>
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<td>4.7</td>
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<td>PLANT * MHT</td>
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<td>4.7</td>
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<tr>
<td>WHSE * MHT</td>
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<td>4.7</td>
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<tr>
<td>Error</td>
<td>2879</td>
<td>3.3</td>
</tr>
</tbody>
</table>
either four, zero, or one day holding times, as indicated in Figure 14. The lowest cost system for the hypothetical data was four days holding time from plants. System structures using consolidation had greater mean delivery times than did the similar direct shipment system; that is, one and four day holding time from plants had greater mean delivery times than direct shipments from plants. Similarly, one and four day holding times from warehouses had longer delivery times than direct shipments from warehouses. While delivery time variance for four day holding time from plants was significantly greater than other system structures, the one day holding time was not significantly greater than all of the remaining structures. Therefore, the hypothesis that consolidation from plants would not result in greater delivery time variance had to be accepted. These results were consistent with the major findings of the main study and lend some support to the generalizability of results to different demand patterns and distributions of weights of orders.

Cost versus Service

The simulations used warehouse or pooling configurations constructed to provide the lowest cost systems without a service constraint. Next, a service constraint of six days average delivery time was imposed to determine which structure would be used in the discriminant analysis. Service constraints of five, six, and seven days were examined. With no service constraint, the four day consolidation from plants was always the lowest cost system, although the one day holding time system was sometimes not significantly different from the four day system cost
<table>
<thead>
<tr>
<th></th>
<th>Cost per Hundredweight</th>
<th>Mean Delivery Time</th>
<th>Delivery Time Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest value structure</td>
<td>5</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Lowest value structure</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Notes: (1) The lowest value structure provides the lowest cost, shortest delivery time, and lowest delivery time variance respectively.

(2) Vertical lines indicate that structures are not significantly different.

(3) 1 = plant, 0 days holding time  
2 = plant, 1 day holding time  
3 = plant, 4 days holding time  
4 = warehouse, 0 days holding time  
5 = warehouse, 1 day holding time  
6 = warehouse, 4 days holding time

Figure 14. Results of Real Data Simulations
as can be seen in Table 26. When a seven day mean delivery time limit was imposed, some direct shipments from plants were selected because of the longer delivery times for the one and four day consolidations from plants. Restricting mean delivery time to six days resulted in all but one of the structures being selected, as illustrated in Table 17 on page 92 in the discriminant analysis section. One day holding time from warehouses never had lower costs than did another system structure. A different pattern of structures occurred when a five day constraint was employed, but in some cases no system structure provided a mean delivery time of five days or less. The six day delivery constraint was selected for use in the discriminant analysis to give a range of system structures and as the longest period considered managerially acceptable if a service constraint of mean delivery time was considered.

An examination of transportation costs alone indicated that all systems except direct shipment from plants and one day holding from warehouses provided the least cost system for some combinations of the demand and product characteristics studied as demonstrated in Table 27. This finding suggested that four systems could provide the lowest transportation costs. However, the inclusion of carrying costs for transit time and additional costs for decentralized storage could exceed transportation cost advantages. The result was a different system selected for lowest distribution cost.

Examination of the two measures of customer service, mean delivery time and delivery time variance, indicated that the system that provided the lowest mean delivery time was not necessarily the system with the lowest delivery time variance. The lowest mean delivery time structure was almost always unconsolidated shipments from warehouses, as is indicated in Table 28. However, this structure did not always have
Table 26
LOWEST COST STRUCTURES

<table>
<thead>
<tr>
<th>Product Class</th>
<th>Geographic Demand</th>
<th>Mean Order Weight</th>
<th>Total Annual Orders</th>
<th>East</th>
<th>Central</th>
<th>South</th>
<th>East</th>
<th>Central</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Population</td>
<td>500#</td>
<td>50,000</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1500#</td>
<td>50,000</td>
<td>3</td>
<td>3,4</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mfgr. Value+</td>
<td></td>
<td>500#</td>
<td>50,000</td>
<td>3</td>
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<td>3</td>
<td>3</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>250,000</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>1500#</td>
<td>50,000</td>
<td>3</td>
<td>3,4</td>
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<td></td>
<td></td>
<td>250,000</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1  Population 500#  50,000  3  3  3
|               |                   | 250,000          | 3                   | 3    | 3       | 3     | 3    |         |       |
|               |                   | 1500#            | 50,000              | 3,2 | 3,2     | 3     | 3    |         |       |
| Mfgr. Value+  |                   | 500#             | 50,000              | 3,2 | 3       | 3     | 3    |         |       |
|               |                   | 250,000          | 3                   | 3    | 3       | 3     | 3    |         |       |
|               |                   | 1500#            | 50,000              | 3,2 | 3,2     | 3     | 3    |         |       |
|               |                   | 250,000          | 3                   | 3    | 3       | 3     | 3    |         |       |

2  Population 500#  50,000  3  3  3
|               |                   | 250,000          | 3                   | 3    | 3       | 3     | 3    |         |       |
|               |                   | 1500#            | 50,000              | 3,2 | 3,2     | 3     | 3    |         |       |
| Mfgr. Value+  |                   | 500#             | 50,000              | 3   | 3       | 3     | 3    |         |       |
|               |                   | 250,000          | 3                   | 3    | 3       | 3     | 3    |         |       |
|               |                   | 1500#            | 50,000              | 3,2 | 3,2     | 3     | 3    |         |       |
|               |                   | 250,000          | 3                   | 3    | 3       | 3     | 3    |         |       |

3  Population 500#  50,000  3  3  3
|               |                   | 250,000          | 3                   | 3    | 3       | 3     | 3    |         |       |
|               |                   | 1500#            | 50,000              | 3,2 | 3,6,2   | 3,6,2 | 3,6,2 |
| Mfgr. Value+  |                   | 500#             | 50,000              | 3   | 3       | 3     | 3    |         |       |
|               |                   | 250,000          | 3                   | 3    | 3       | 3     | 3    |         |       |
|               |                   | 1500#            | 50,000              | 3,2 | 3,6,2   | 3,6,2 | 3,6,2 |
|               |                   | 250,000          | 3                   | 3    | 3       | 3     | 3    |         |       |

Note: 1 plant - 0 days holding
2 plant - 1 day holding
3 plant - 4 days holding
4 warehouse - 0 days holding
5 warehouse - 1 day holding
6 warehouse - 4 days holding
### Table 27
LOWEST TRANSPORTATION COST STRUCTURES

<table>
<thead>
<tr>
<th>Product Class</th>
<th>Geographic Demand</th>
<th>Mean Order Weight</th>
<th>Total Annual Orders</th>
<th>Plant Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>East</td>
</tr>
<tr>
<td>All</td>
<td>Population</td>
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<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Mfgr. Value+</td>
<td>500#</td>
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<tr>
<td></td>
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<td>250,000</td>
<td>3</td>
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</tr>
<tr>
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<td>1500#</td>
<td>50,000</td>
<td>4</td>
</tr>
<tr>
<td></td>
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<td>250,000</td>
<td>3</td>
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</tr>
<tr>
<td>60</td>
<td>Population</td>
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<tr>
<td></td>
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<td>250,000</td>
<td>3</td>
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<tr>
<td></td>
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<td>250,000</td>
<td>3,2</td>
<td>3,2</td>
</tr>
<tr>
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<td>Mfgr. Value+</td>
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<tr>
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<td></td>
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</tr>
<tr>
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<td>Mfgr. Value+</td>
<td>500#</td>
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<tr>
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</tr>
<tr>
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<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1500#</td>
<td>50,000</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>250,000</td>
<td>3,6</td>
<td>3,6</td>
</tr>
</tbody>
</table>

Notes:
(a) Additional structures listed are within 10¢/cwt of lowest cost structure.
(b) Carrying costs for in-transit inventory not included.
(c) Structures:
1 plant - 0 days holding
2 plant - 1 day holding
3 plant - 4 days holding
4 warehouse - 0 days holding
5 warehouse - 1 day holding
6 warehouse - 4 days holding
Table 28
LOWEST MEAN DELIVERY TIME IN DAYS ($\alpha = .01$)

<table>
<thead>
<tr>
<th>Product Class</th>
<th>Geographic Demand</th>
<th>Mean Order Weight</th>
<th>Total Annual Orders</th>
<th>East</th>
<th>Central</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Population</td>
<td>500#</td>
<td>50,000</td>
<td>4.0</td>
<td>4.0</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1500#</td>
<td>50,000</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500#</td>
<td>250,000</td>
<td>3.6</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1500#</td>
<td>250,000</td>
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<td>2.7</td>
<td>2.7</td>
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<td>500#</td>
<td>50,000</td>
<td>3.7</td>
<td>3.7</td>
<td>3.7</td>
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<tr>
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<td></td>
<td>1500#</td>
<td>50,000</td>
<td>3.0</td>
<td>3.1</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500#</td>
<td>250,000</td>
<td>3.0</td>
<td>3.0</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1500#</td>
<td>250,000</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
</tr>
</tbody>
</table>

| 1              | Population        | 500#              | 50,000              | 5.3  | 5.7 (1,4) | 5.5  |
|               |                   | 1500#             | 50,000              | 5.8  | 5.3      | 5.0   |
|               |                   | 500#              | 250,000             | 4.3  | 5.2 (4,5) | 4.9 (5) |
|               |                   | 1500#             | 250,000             | 3.5  | 4.1 (5)  | 3.7 (5) |
|               | Mfgr. Value+      | 500#              | 50,000              | 4.8  | 5.1 (1,4) | 5.5   |
|               |                   | 1500#             | 50,000              | 5.3  | 4.7      | 4.8   |
|               |                   | 500#              | 250,000             | 4.0  | 4.4      | 4.5 (5) |
|               |                   | 1500#             | 250,000             | 3.0  | 3.7 (4,5) | 3.5 (4,5) |

| 2              | Population        | 500#              | 50,000              | 5.1  | 5.7 (1,4) | 5.3  |
|               |                   | 1500#             | 50,000              | 4.3  | 5.1      | 4.4   |
|               |                   | 500#              | 250,000             | 3.8 (4,5) | 3.6 | 3.7   |
|               |                   | 1500#             | 250,000             | 3.1 (4,5) | 3.1 | 3.1   |
|               | Mfgr. Value+      | 500#              | 50,000              | 4.7  | 5.1 (1,4) | 4.8   |
|               |                   | 1500#             | 50,000              | 3.6  | 4.3      | 3.6   |
|               |                   | 500#              | 250,000             | 3.2  | 3.3      | 3.4   |
|               |                   | 1500#             | 250,000             | 2.6 (4,5) | 2.6 | 2.7 (4,5) |

| 3              | Population        | 500#              | 50,000              | 3.7  | 4.6      | 4.9   |
|               |                   | 1500#             | 50,000              | 3.3  | 3.5      | 3.6   |
|               |                   | 500#              | 250,000             | 2.7  | 3.0      | 3.1   |
|               |                   | 1500#             | 250,000             | 2.5  | 2.6      | 2.9   |
|               | Mfgr. Value+      | 500#              | 50,000              | 4.0  | 4.4      | 4.4   |
|               |                   | 1500#             | 50,000              | 3.0  | 3.2      | 3.2   |
|               |                   | 500#              | 250,000             | 2.5  | 2.6      | 2.6   |
|               |                   | 1500#             | 250,000             | 2.3  | 2.3      | 2.5   |

Note: Structure 4, no consolidation from warehouses, usually provides the lowest delivery time. When other structures are not statistically different from 4, both 4 and the structure number appear in parentheses. Structure 5 was lowest in four cases.

7 = plant - 0 days holding time
5 = warehouse - 4 days holding time
the lowest delivery time variance, as is indicated in Table 29.

Comparison with the lowest cost structure, which was four days consolidation from plants, indicated that no structure had the lowest cost, lowest mean delivery time, and lowest delivery time variance. A similar finding resulted when the six system structures, represented as five dummy variables, were regressed on cost per hundredweight, mean delivery time, and delivery time variance as compared in Table 30. The rank order of the structures and the structure with the lowest value varied across the three dependent variables. These results suggest that tradeoffs among the three measures of system performance are necessary to the selection of a distribution system. Previous researchers, such as Masters, had confirmed the conflict between low cost and service level.

A large number of paired comparisons was implied in this section to ascertain the lowest distribution cost, transportation cost, mean delivery time, and delivery time variance for each combination of demand and product levels. While the preliminary analysis indicated that there was reasonable power for the data set, making so many tests suggests the possibility that some tests would appear significant by chance. Therefore, the results regarding transportation cost, mean delivery time, and delivery time variance have been provided for illustration of the patterns observed in the data without a specific claim of significance of the results.
<table>
<thead>
<tr>
<th>Product Class</th>
<th>Geographic Demand</th>
<th>Mean Order Weight</th>
<th>Total Annual Orders</th>
<th>Plant Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>East Structure</td>
<td>Central Structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Variance</td>
<td>Variance</td>
</tr>
</tbody>
</table>

| All          | Population       | 500# 50,000      | 4 8.4 4.5 8.9 4 8.4 | 1500# 50,000      | 4 8.7 4.5 8.9 4.5 9.1 | 1500# 250,000      | 5 9.1 5 7.7 5 7.7 |
| Mfgr. Value+ | 500# 50,000      | 4.5 8.6 5 7.9 5 7.9 | 1500# 50,000      | 4.5 7.6 4.5 7.7 4.5 7.6 | 1500# 250,000      | 4.5 8.0 4.5 8.2 4.5 8.1 |
| 1            | Population       | 500# 50,000      | 4 12.7 5 10.5 1.4 5 7.2 | 1500# 50,000      | 5.6 13.5 5 8.6 5 6.0 | 1500# 250,000      | 5 10.0 5 8.7 5 5.6 |
| Mfgr. Value+ | 500# 50,000      | 2.4 14.1 5 10.1 1.5 7.0 | 1500# 50,000      | 4 10.3 5 8.6 1.4 5 6.8 | 1500# 250,000      | 5.6 11.2 5 7.0 5 5.2 |
| 2            | Population       | 500# 50,000      | 5 10.0 2.5 11.4 1.4 7.2 | 1500# 50,000      | 5 10.7 5 9.1 5 5.8 | 1500# 250,000      | 5 8.2 5 7.1 1.2 5 7.3 |
| Mfgr. Value+ | 500# 50,000      | 5 8.9 2.3 10.2 1 6.8 | 1500# 50,000      | 5 8.2 5 8.6 4.5 6.1 | 1500# 250,000      | 4 10.7 5 7.2 1 6.5 |

124
<table>
<thead>
<tr>
<th>Product Class</th>
<th>Geographic Demand</th>
<th>Mean Order Weight</th>
<th>Total Annual Orders</th>
<th>Plant Location</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Population</td>
<td>500# 50,000</td>
<td>4</td>
<td>East Structure</td>
<td>6.3</td>
<td>5</td>
<td>7.4</td>
<td>5</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1500# 50,000</td>
<td>4,5</td>
<td></td>
<td>8.4</td>
<td>4</td>
<td>7.6</td>
<td>1</td>
<td>6.7</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>500# 250,000</td>
<td>4</td>
<td>Central Structure</td>
<td>5.9</td>
<td>4</td>
<td>5.8</td>
<td>1,2</td>
<td>7.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1500# 250,000</td>
<td>4</td>
<td></td>
<td>7.5</td>
<td>5</td>
<td>7.3</td>
<td>1,3</td>
<td>7.1</td>
<td></td>
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<tr>
<td></td>
<td>Mfgr. Value+</td>
<td>500# 50,000</td>
<td>5</td>
<td>South Structure</td>
<td>9.2</td>
<td>5</td>
<td>7.2</td>
<td>1,4,5</td>
<td>7.2</td>
<td></td>
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<td>1500# 50,000</td>
<td>4,5</td>
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<td>500# 250,000</td>
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<td>1500# 250,000</td>
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<td>7.3</td>
<td>5</td>
<td>6.8</td>
<td>1,5</td>
<td>7.2</td>
<td></td>
</tr>
</tbody>
</table>

1 = Plant - 0 holding days  
2 = Plant - 1 holding day  
3 = Plant - 4 holding days  
4 = Warehouse - 0 holding days  
5 = Warehouse - 1 holding day  
6 = Warehouse - 4 holding days
Table 30
SYSTEM STRUCTURE REGRESSED ON COST PER HUNDREDWEIGHT,
DELIVERY TIME, AND DELIVERY TIME VARIANCE WEIGHT.
(Full Data Set of 2880 Observations)

<table>
<thead>
<tr>
<th>System Structure</th>
<th>Cost per Hundredweight (B) estimated cost ($)</th>
<th>Delivery Time (B) estimated time (days)</th>
<th>Delivery Time Variance (B) estimated time variance (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Intercept-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>plant - 0 days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>holding time</td>
<td>31.44</td>
<td>6.01</td>
<td>12.30</td>
</tr>
<tr>
<td>2: plant - 1 day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>holding time</td>
<td>-1.44</td>
<td>.33</td>
<td>-1.27</td>
</tr>
<tr>
<td>3: plant - 4 days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>holding time</td>
<td>-2.07</td>
<td>.78</td>
<td>.19</td>
</tr>
<tr>
<td>4: warehouse -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 days holding</td>
<td>-1.03</td>
<td>-2.25</td>
<td>-2.82</td>
</tr>
<tr>
<td>time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5: warehouse -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 day holding</td>
<td>-0.01</td>
<td>-1.63</td>
<td>-3.89</td>
</tr>
<tr>
<td>time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6: warehouse -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 days holding</td>
<td>-.36</td>
<td>-.78</td>
<td>-2.02</td>
</tr>
<tr>
<td>time</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

The results of tests of the formal hypotheses indicated that the hypotheses concerning cost and delivery time variance were not always supported but those associated with delivery time generally were supported. Shipping directly from the plants was not always the most expensive means of distribution for the demand and product levels studied. Delivery time variance for consolidation from plants with four days holding time was significantly greater than delivery time variance for other systems in thirty-two of the ninety-six cells investigated. Delivery time variance for one day holding time from plants was significantly greater than other systems in only fourteen instances. Thus, the hypothesis that consolidation increases delivery time variance was not unconditionally supported. The hypotheses that consolidation would increase mean delivery time over unconsolidated structures were supported at the aggregate level and for most of the individual cells.

Discriminant analysis of the lowest cost systems subject to a six day mean delivery time constraint yielded two functions. The first function indicated the importance of the relationship between plant location and dispersion of demand. Plants located further from the market were forced to use warehouses to meet the delivery time constraint. The second function indicated the importance of using a pooling strategy if class 100 product was shipped instead of classes 60 and 77.5. Seventy-three percent of the cases were correctly classified using the two functions. Results of the regression analyses suggested that mean order weight was the most important variable for determining cost for the total data set, for the observations used in the discriminant analysis, and
for each of the system structures except direct shipment from plants. Plant location was the most important variable in determining delivery time if products were shipped from plants. For products shipped from warehouses, mean order weight, total annual orders, and product class were important. These variables influenced the warehouse configuration which, in turn, influenced delivery time. The implications of these results are discussed in Chapter V.
CHAPTER V

CONCLUSIONS

This chapter consists of four sections. First, research questions and methodology are reviewed. Second, conclusions based on the formal hypotheses tests are presented. The third section contains the implications of the study for logistical theory and practice. The final section contains additional research topics suggested from the results of this research effort.

Review of the Study

Increasing pressures of inflation and rising costs of capital have prompted reassessment of distribution systems to determine if different strategies might be more cost effective, given service level constraints. Two possible strategies were freight consolidation and decentralized deployment of inventory using field distribution centers. This research sought to compare these two alternatives which have not previously been directly compared. Additionally, this research has sought to extend the freight consolidation literature by examining multiple products and multiple plants in the distribution system.

The objectives of the research were to compare freight consolidation with remote stocking for high valued industrial goods and to evaluate whether the results of previous freight consolidation research, which investigated one product class shipped from one plant, could be
generalized to the multi-product multi-plant situation. The first research question prompted by these objectives was whether the distribution systems differed when measured on distribution costs, mean delivery time, and delivery time variance. Previous freight consolidation research suggested that costs would be reduced, mean delivery time would generally increase, and delivery time variance would generally not exceed that of direct shipments from plants. These conclusions were investigated and extended by comparing freight consolidation with systems using warehouses as well as direct shipment.

A second question considered whether certain combinations of the demand and product variables would indicate that one distribution system might be preferred over the others. Six distribution systems of interest were defined by indicating 1) whether warehouses were used and 2) the number of days an order could be held before shipment. Orders could be held up to zero, one, or four days. Zero holding days did not employ any freight consolidation. Thus the following possible systems were investigated:

1) shipment from plants with zero days holding time,
2) shipment from plants with one day holding time,
3) shipment from plants with four days holding time,
4) shipment from warehouses with zero days holding time,
5) shipment from warehouses with one day holding time,
6) shipment from warehouses with four days holding time.

The third question dealt with the relative influence of the two system structure variables listed above and five demand and product characteristics in determining the distribution costs. The five factors
investigated were number of annual orders, mean order weight, product class, plant location, and geographic distribution of demand. Two levels of the number of annual orders were considered: 50,000 and 250,000 orders. The mean order weight for a particular shipment was selected from a normal distribution with a mean equal to either 500 or 1500 pounds and a standard deviation equal to the mean. The product class factor had four levels. Three of the levels represented each of three motor carrier shipment classes. The combination of all three classes generated the fourth level. The three shipment classes were 60, 77.5, and 100. The fourth level was the multi-product class. Each product was shipped from a different plant; three plants were used when the fourth level was simulated. Only one plant was used for simulations involving one product class. The three plant locations considered in this study were Newark, New Jersey, Columbus, Ohio, and Dallas, Texas. These three cities permitted investigation of a plant located on the east coast, a plant in the midwest, and a plant in the South. The last factor investigated was geographic distribution of demand either by population or by manufacturer's value added. The 150 largest Standard Metropolitan Statistical Areas of each demand served as demand points for the simulations. In addition, actual shipment data from a major industrial corporation provided another distribution of demand for comparison with the artificial data using the above demand and product characteristics.

The methodology for investigating the research questions consisted of several steps:
1) A program to select pooling points or warehouses;

2) A simulation to determine the cost, mean delivery time, and delivery time variance for each system;

3) Multivariate analyses of variance to determine the lowest cost systems; and

4) Regression and discriminant analyses.

The results of these procedures were used to identify relationships between the demand and product characteristics and the choice of distribution system. Khumawala's branch and bound integer programming algorithm, presented in Appendix A, was used to generate lowest cost warehouse or pooling point configurations. These configurations were used for the simulations of the different distribution system structures.

An event-oriented Monte Carlo model was used to simulate the six systems under the different levels of the demand and product characteristics. Carrying costs were assessed on all products. Eight turnovers per year were assumed and the products were valued at $400 per hundredweight. Additional carrying costs were assessed for time in transit. For the systems using warehouses, carrying costs for increased safety stock due to decentralization were charged as well as handling and storage costs. Published motor carrier transportation rates determined the shipment costs between points. The model formulation appears in Appendix E, and additional assumptions underlying the model are in Appendix F.

The results of the simulations were analyzed using multivariate analysis of variance and the univariate Duncan's multiple range tests. These analyses were used to assess differences across systems in cost
per hundredweight, mean delivery time, and delivery time variance in order to test the formal hypotheses of the first research question. The second and third research questions were investigated by the use of discriminant and regression analyses. Two discriminant functions were derived for the lowest cost systems subject to a maximum mean delivery time of six days. Regression analyses were performed on the entire data set, the system structures used in the discriminant analysis, and on each individual system. The results of these regressions were compared by correlation. Kendall's tau was used to determine whether different demand and product characteristics influence distribution costs of different systems.

With this brief overview of the research intentions and methodology, the formal conclusions of specific research hypotheses are presented.

**Hypothesis Test Results**

Discussion of the results of the formal hypothesis tests reported in Chapter IV is limited to interpretation of the test results and possible explanations for the outcomes based on the logic of the simulation model and input variables.

**Cost**

Distribution costs were hypothesized to be greatest for direct shipment from plants. This hypothesis was not supported for every combination of product and demand characteristics or at the aggregate level. For lower total shipping weight, direct shipment from plants was not necessarily the most expensive system because the warehouse
structures using consolidation were as expensive as direct shipment from plants. Additional carrying costs for holding the order and warehousing costs eliminated the savings in transportation to the warehouse and the pooled transportation costs to the demand point.

A system using four days holding time from plants provided the lowest cost structure. The carrying costs incurred from holding the inventory longer before shipment were less than transportation savings over a direct shipment system. This finding agrees with Masters' study of transportation costs but may not support Jackson's finding that order cycle costs were greater than direct shipment costs when a system received fifty orders per day.¹ This level represented an annual volume of 12,500 orders compared with the lowest volume of 16,000 for the present study.

The difference in results between the present study and Jackson's may be the treatment of carrying costs and the number of pooling points used in addition to the slight difference in volume of goods shipped. Jackson assigned a charge for the increase in costs incurred at pooling points because of consolidation. The present study also assessed carrying costs at pooling points, and in contrast with previous studies, it included carrying costs for goods in transit. The high valued product used in the present study would emphasize carrying cost differences. An additional difference is the number of pooling points used.

Both Masters and Jackson selected specific numbers of pooling points, whereas the present study searched for the number as well as the locations of pooling points. Thus, a difference in the results of this research from previous efforts was possible because of differences in model formulation. One should note, however, that the findings of this study were generally consistent with results of previous studies despite differences in models.

Delivery Time

The hypotheses that mean delivery time for structures using freight consolidation was greater than mean delivery time for unconsolidated structures was generally supported. The additional delivery time incurred by holding orders and assessing a one day break bulk time for pooled shipments was greater than any time saved by shipping larger orders. One exception was shipment of goods from a single plant in Newark, New Jersey, where for the product classes of 60 and 77.5, mean delivery time for a one day holding time structure was not significantly longer than for direct shipment.

The published freight rates for the lower product classes from Newark did not provide sufficient savings in transportation costs to support as many pooling points as did the class 100 rate differences. Fewer pooling points resulted in larger shipments which travelled to the pooling points faster and compensated for the holding time to build the shipments. Fewer pooling points also resulted in more direct shipments from Newark for which pooling was not justified. While these same statements can be made about the other plants, the results for the Newark plant appeared to be an anomaly of plant location and the freight
rates. The results suggested that for a single source located on the East Coast, a one day holding structure would not sacrifice delivery time for lower product classes.

Another exception occurred for large volumes of product shipped through warehouses with one day holding time compared with direct shipment from warehouses. The exceptions occurred for the highest annual volume of orders and the highest weight category. The high volumes of goods being shipped increased the probability of orders being consolidated into larger shipments which could experience shorter transit times. These shorter transit times could balance out the holding time and the one day break bulk time assessed for pooled shipments. Transit time for a one day holding strategy would not be significantly longer than direct shipment from warehouses.

With the exceptions noted, delivery time was generally longer for systems using consolidation than for direct systems. Reductions in transit time due to larger shipments was less than the increases in delivery time for holding days and break bulk time.

**Delivery Time Variance**

The hypothesis that delivery time variance for pooled shipments from plants would be greater than delivery time variance for all other structures was not supported. This finding was consistent with Masters' conclusion that delivery time variance was not necessarily increased with the use of pooling. A closer examination of the results suggested that the one day holding structure did not necessarily have greater delivery time variance but that a four day holding strategy could increase delivery time variance over other structures.
The conditions where delivery time variance for consolidation from plants exceeded variance from other structures were the low mean order weight and the low annual volume shipments from all plants. With the lower volume divided among the three plants, the actual volume through a pooling point from a plant would be the lowest of the volumes studied. In these cases, orders would be held longer before shipment than in higher weight-volume categories, thereby increasing delivery time variance.

**Implications of the Research**

The present research suggested several implications for the development of logistical theory and practice. Theoretical considerations are addressed first, followed by management considerations for the selection of distribution systems considering cost and service level. The study examined single echelon warehouse and pooling systems involving high valued products with each product class produced at a separate plant.

**Theoretical Considerations**

The theoretical objectives stated in Chapter I were to compare warehousing with freight consolidation systems and to extend the freight consolidation literature. A methodology was developed for such a comparison. The lowest cost configuration of warehouses or pooling points was selected for the different systems and then simulations were run using these configurations. This approach contrasts with selecting one set of locations to serve as either warehouses or pooling points for the conditions being investigated. In order to compare different
systems for distributing products, the best configuration for each system was necessary. The results of the present research indicated that different configurations were indeed generated for the different systems.

The second objective was to extend the freight consolidation literature by investigating different demand and product conditions than had previously been investigated. These differences were a different distribution of demand, consideration of high valued industrial products, inclusion of in-transit carrying costs, and investigation of multi-product/multi plant situations. The general conclusion reached was that for the systems studied, freight consolidation always provided the lowest cost system even when penalized in terms of carrying cost for additional holding days and break bulk days. Specific results concerning the cost-service tradeoff and the relative importance of the product and demand characteristics in determining cost per hundredweight are now discussed and compared with previous research.

**Cost and Service Level**

Without a service level constraint, high valued product was moved less expensively using four days holding time from the plants. Direct shipments from plants were smaller and had longer transit times, thereby incurring higher total in-transit costs than larger pooled shipments.

Imposing service level constraints of maximum mean delivery time altered the choice of system. High volume systems supported more warehouses and thus were located closer to customer demand. Changing the mean delivery time requirements by one day from eight days to seven, and seven days to six, altered the choice of systems in many cases
away from plant consolidation strategies. The shift was toward warehousing alternatives.

The lowest cost system was not the system providing the shortest delivery time or necessarily providing the lowest delivery time variance. Direct shipment from warehouses was almost always the shortest delivery time but four days holding time from the plants was the least expensive. Masters found that the lowest cost systems were not the shortest delivery time systems when only direct shipments and consolidation from plants were considered. In his study, pooling point configurations were generated to meet objectives of lowest transportation cost, shortest mean delivery time, or lowest delivery time variance. He found that the configuration which minimized cost was not the configuration which achieved shortest delivery time. Thus, lowest cost and shortest delivery time systems vary either within consolidation alternatives or across consolidation and warehousing alternatives.

Influence of Demand, Product, and Structure Variables on System Costs

The third research question concerned the importance of structure, demand, and product characteristics in determining distribution costs. Of demand and product variables studied, mean order weight was the most important for the entire data set. Distribution cost per hundredweight decreased with an increase in the mean order weight. The additional volume helped create cost effective pooled shipments which could be shipped less expensively than smaller shipments or alone.

Mean order weight was the most important variable in all structures except for direct shipment from plants. Mean order weight was also
most important in determining transportation costs in Masters' study where it comprised 94 percent of the variation. Comparison with the Jackson study was not possible since mean order weight was not varied. Masters studied mean order weights of 100, 500, and 1000 pounds. Savings were greatest for the lower mean order weights. The present research suggested that the higher mean order weight of 1500 pounds could also experience cost savings from a consolidation strategy.

Product class was the second most important factor in the research. As the shipment class changed from 60 to 77.5 to 100, distribution costs increased because the transportation rates were greater for each higher class until a full truckload rate was reached. The multi-product average rates fell around the 77.5 level because each product had equal demand. Neither Masters nor Jackson studied variation in product class but used only class 100 which was the most expensive product to ship in the present study. Classes 60 and 77.5 cost less per hundredweight for comparable weight categories and the differences in costs per hundredweight between successive weight breaks were less than for class 100. Nevertheless, for the product value investigated, the lower classes also benefited from consolidation strategies.

Total annual orders influenced distribution costs for all structures except direct shipment from plants. Since no consolidation was attempted with this structure, the number of orders would not affect cost per hundredweight. The number of annual orders accounted for 29 percent of the explained variance in Jackson's study, but for only 2.7 percent in Masters' study and 6.8 percent in the present study. The strong influence of mean order weight in both Masters' and the present study reduced the relative influence of total annual orders. Still
this factor was twice as important as plant location, geographic distribution of demand, or any of the interactions.

Plant location explained more than three percent of the variance and was a factor in two of the four significant interactions. If only one plant was located on the periphery of the market or was far from market concentration, warehousing was necessary to meet the six day mean delivery time constraint. Mean delivery time for direct and for one day holding time shipments from the Newark plant were not statistically different. Since savings resulted from consolidation, a one day holding time could be used to save transportation costs without increasing delivery time. When the Dallas plant supplied part or all of the product, warehousing was almost always necessary to reach the market in an average of six days or less whether demand was distributed as population or as manufacturer's value added. Pooling from the Columbus plant was a viable alternative when the service level constraint was imposed. The more central location of Columbus, in comparison with the other plants, resulted in shorter delivery times for shipments from that plant.

Two discriminant functions were developed using the lowest cost systems subject to a six day mean delivery time constraint. The dummy variables which represented plant location and geographic distribution of demand were the major components of the first of the two functions. The combination of these two factors indicated the importance of the geographic relationship of supply and demand when a service constraint was imposed. Additional volume flowing through the system did not compensate for the wide dispersions of plants from their markets. The group centroid values of the classification functions reflected both
whether warehouses were used and whether pooling was used. For the first function, whether warehouses were used was more important than whether pooling was used since the function appeared to reflect the delivery time constraint imposed. Whether pooling was used was more important in the second function.

The structure variables of the use of warehouses and the maximum days an order could be held were not important as main effects in the regression using all the data, but their interaction, which defined the six system structures, accounted for 4.6 percent of the variation in Table 20 on page 103. This value made system structure the fourth most important of the main effects and interactions in determining system cost. Thus, mean order weight had the highest explained variance, followed in order by product class, total annual orders, system structure, and plant location.

A final consideration was the relationship of single-plant, single-product results to multi-plant, multi-product results. In terms of pooling points, the results appear to be generalizable, particularly given the formulation of the pooling simulations. Each product class was simulated separately with the assumption that each class was shipped separately. If an advantageous freight-all-kinds rate can be negotiated, then pooling would be even more attractive because larger volumes could be accumulated over shorter periods of time. Since the model used to generate the hypothetical data always had one product produced at one plant, the assumption did not eliminate any pooling opportunities.

In the analysis of the actual industrial shipments, more than one product could be shipped from a plant but each product class was cumulated separately. The plant locations for the actual data were all in the
midwest to midsouth. The lowest cost systems were those which shipped
directly from the plants, either with or without consolidation. Since
the plants were all centrally located, the results more closely paral-
lel the results of the hypothetical data with one plant centrally
located. Consolidated shipments from the Columbus plant were able to
meet the six day service level constraint for the volume and product
classes of the actual shipment data.

Managerial Considerations

The contributions to the practice of logistics lie in the impli-
cations for designing distribution systems for high valued industrial
products. The present study has considered both warehousing and freight
consolidation alternatives. The results indicate that 1) a pooling
strategy should not be overlooked and 2) customer service requirements
may need reassessment in light of the distribution system selected.

Freight Consolidation Strategy

A strategy of shipping products from plants and permitting up to
four days to accumulate a consolidated shipment was always the lowest
cost system. The few exceptions not different in cost from the four day
holding strategy from plants were for 375 million pounds, the highest
volume shipped. The exceptions were usually for a system using one day
holding time from plants. Thus, for the high valued product investi-
gated, a pooling strategy should not be rejected out of hand. The pro-
duct was valued at $400 per hundredweight with carrying costs of 30
percent.
Even for the reasonably wide range of shipment volumes, mean order weights, plant locations, and shipment classes investigated, the four day holding strategy from plants was least expensive. The implication of these results is that the number of warehouses can be reduced or eliminated to improve asset productivity. In addition, inventory investment may be reduced through central stocking and at least a part of the remote safety stock may be eliminated. Thus, if the system currently in place employs warehouses, then management may wish to consider pooling strategies for at least a portion of the market. With the high interest rates in existence, a consolidation strategy should be examined.

Customer Service Considerations

A shift to central stocking and a holding strategy of up to four days to build economical shipments may increase order cycle time with the increase in delivery time. The differences in mean delivery time were statistically significant in the present study, but from a practical standpoint the differences may not be judged to be great. One day holding strategies from either plants or warehouses were usually no more than one day longer than the respective direct shipment strategies. Four day holding strategies were usually no more than two days longer than direct strategies. Those instances where mean delivery time was greater than one or two days applied to the very lowest volume of 16,000 orders for each product shipped from warehouses. Thus, even a consolidation strategy of holding orders up to four days probably will not increase mean delivery time more than two days and substantial cost savings may result.
Management may wish to consider whether an increase in order cycle time of one or two days will jeopardize future business. If another part of the order cycle time cannot be reduced, then the customers' sensitivity to delivery time must be assessed.

A potential problem with shifting from remote stocking to central stocking is the increase in the customers' inventories to adjust for longer and possibly more variable lead times. The reduction in the shipper's inventory may be shifted to the customers. A central stocking policy with four days holding time may negatively affect demand if not handled properly by the sales force and management. Negotiating contracts with carriers for more consistent service and imposing regularity in placement of orders by customers would help to control order cycle time and to overcome the concern about longer lead times.

If a short delivery time is necessary, then remote stocking may be required when the plants are located on the periphery of demand. In many instances, Dallas and Newark could not meet the average delivery time of six days when a holding strategy was used on shipments from plants. A partial remote stocking policy may be needed to satisfy demand at great distances from these plants. Centrally located plants may be able to provide desired service levels for customers so that a consolidation strategy would be reasonable for all customers.

Designing a physical distribution system is a difficult task. One of the goals of the present study was to provide added information and insight into designing such systems. For companies which ship primarily high valued products, the present study suggests that a consolidation policy should be considered for improving asset productivity.
Summary

The research effort has resulted in a model to simulate a random stream of orders and order weights for systems which differ on the total number of orders, the mean order weight, the product class, the plant location, and the geographic distribution of demand. The major contribution of the present study is the comparison of freight consolidation strategies with direct shipment from either plants or warehouses. The results of the research indicate that, when compared with direct shipment or use of warehouses, freight consolidation was feasible for shipping high valued products with mean order weights up to 1500 pounds, assuming normally distributed order weights. Freight consolidation may also be feasible for order volumes as low as 16,000 orders of 500 pounds, or 8 million pounds annually.

The other results of the research tend to support the results of previous researchers in that consolidation reduced costs and increased mean delivery time. Holding orders up to four days tended to increase delivery time variability, but a one day holding strategy was not necessarily more variable than other systems. This result suggested that while a four day holding strategy could reduce distribution costs, this savings must be weighed against increased delivery time and variance. Previous research concerned with freight consolidation indicated that a consolidation strategy would reduce costs for shipment class 100 over direct shipments. This study suggested that lower shipment classes may also experience savings over both direct shipment and warehouse systems.
Thus, the present research has served 1) to extend the findings of previous freight consolidation research and 2) to suggest a methodology for comparing a wider range of distribution alternatives than has previously been studied. Specifically, the present research compared freight consolidation with remote stocking strategies. Possible extensions of the research are considered in the next section.

**Suggestions for Future Research**

As this study has sought to answer some questions about freight consolidation and warehouse location system structures, so the effort has also raised additional questions for future consideration. The potential for further study appears substantial, particularly in the area of freight consolidation where little formal research has occurred. The following areas are identified as future research topics or factors to be incorporated in future models:

1. Investigation of minimum pooling point volume. The 5000 pound minimum used in this study did serve to lower average distribution cost. Investigation of values other than those evaluated here is needed.

2. Investigation of the need for warehouses to be located at plant sites. Comparisons of results with and without this restriction may provide some insight to the cost, if any, of such a restriction.

3. Study of consolidation to demand points served directly by plants. The consolidation algorithms assumed direct unconsolidated shipment from the plants. In some cases the plant supplied most of the demand because few potential pooling points met the minimum throughput requirements. Increased savings for the pooling strategies may be
possible if orders are consolidated at the plants as well as at the other pooling points.

4. Investigation of other methods of selecting pooling points. The Khumawala algorithm supplied conceptually reasonable pooling points and was optimizing for the information it was given. The customer zones assigned to pooling points were economically determined. The Maranzana method of selecting pooling points used by Masters provided good solutions even though it was a heuristic technique. A recursive method of determining average pooled shipment weight from a simulation and using the value to set average pooled weights for input into the pooling point location algorithm may result in reduced cost systems.

5. Investigation of additional variable levels. Parameters included in this study will broaden the base of knowledge about freight consolidation in relation to warehousing alternatives. The minimum release weight used for the pooling strategies was a truckload of 40,000 pounds. Considering minimums of 20,000 and 10,000 pounds may suggest a better minimum level for lowest cost systems. Different order weight streams and demand patterns can be studied, particularly distributions that contain wider ranges of order weights. Lower product values may affect differences in costs when pooling is compared with warehouses since product value affects carrying costs in transit and safety stock valuation. Also different warehouse sizes affect the ultimate number of warehouses in a system. This research used 50,000 square feet per warehouse. Using different inventory policies at the warehouses could contrast with the assumption of eight turnovers per year.
6. Investigation of additional pooling strategies. The real data simulation checked whether orders were greater than 20,000 pounds and, if so, determined if direct shipment from the plant would be less expensive than service from a warehouse. This concept could be extended to checking all shipments over 10,000 pounds. Use of freight-all-kinds rates would provide additional opportunities for consolidation across products. The model used to select pooling points or warehouses could incorporate an explicit service level constraint so that pooling points and warehouses are selected to conform to the service level either in absolute limits or by using probabilities. Multiple echelon consolidation systems, scheduled shipping, and using large shipments as seeds to build pooled shipments are additional strategies for consideration.

7. Determination of break even point of consolidation feasibility. Jackson found that pooling was not feasible for 12,500 shipments per year. The present study suggests the bound may be even lower for high valued products with demand distributed according to population or manufacturers' value added. Additional research is needed to locate the break even volume for goods with different valuations.

Embellishments on the distribution systems studied include multiple echelon consolidation systems, comparing consolidation with limited line warehouses rather than the full line systems investigated in this study, expanding to handle more than three plants and three products, and changing parameter values to investigate other distribution conditions. The present research effort has provided an initial step toward evaluating the wide range of distribution systems available to logistics management by comparing warehousing and freight consolidation strategies.
Books and Reports


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APPENDIX A

The Khumawala Branch and Bound Algorithm

Statement of the Problem

Minimize \[ Z = \sum_{ij} C_{ij} X_{ij} + \sum_{i} F_i Y_i \]

subject to

\[ \sum_{i \in N_j} X_{ij} = 1, \quad j = 1, 2 \ldots n, \]

\[ 0 \leq \sum_{j \in P_i} X_{ij} \leq n_i Y_i, \quad i = 1, 2 \ldots m, \]

\[ Y_i = 0 \quad 1 \text{ (integer)}, \quad i = 1, 2 \ldots m, \]

where \( C_{ij} = D_j \cdot t_{ij} \)

\( t_{ij} = \) the per unit cost which includes the FOB cost at the warehouse (i), the warehouse handling cost and the transportation cost from the warehouse to the customer (j),

\( D_j = \) the demand at customer j,

\( X_{ij} = \) the portion of \( D_j \) supplied from warehouse i,

\( F_i = \) the fixed cost associated with warehouse i,

\( N_j = \) set of warehouses which can supply customer j,

\( P_i = \) set of those customers that can be supplied by warehouse i,

\( n_i = \) number of elements in \( P_i \),

\( Y_i = \) potential warehouse location
APPENDIX A (continued)

Branch and Bound Algorithm

Run linear program without integer restrictions \((Z_0)\).

If any \(Y_k\) is fractional, do two reruns for

\[ Y_k = 0 \quad (Z_1, \text{ where } Z_1 > Z_0) \]

and

\[ Y_k = 1 \quad (Z_2, \text{ where } Z_2 > Z_0) \]

\(Z = \min (Z_1, Z_2)\), is the new lower bound.

The upper bound is the lowest \(Z\) value of nodes where all warehouses are integer values (terminal nodes).

The solution is the upper bound when no remaining nonterminal node has a \(Z\) value and upper bound.

Simplification Rules for Solution Efficiency

1. Determine minimum bound for opening a warehouse. Savings from serving customers from other warehouses exceeds fixed cost of location.

2. Reduce number of customers to be assigned to free warehouses, if an open warehouse can serve the customer cheaper.

3. Determine maximum bound on cost reduction for opening a warehouse. The value must be positive.

APPENDIX B

The Geoffrion 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

\( y_k[u_k] \)  the amount of underflow (overflow) of \( \text{VMIN}_k \) [\( \text{VMAX}_k \)], at a penalty rate of \( \text{PL}_k[\text{PU}_k] \), for distribution center \( k \).

\( x_{ijkl} \)  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

\( c_{ijkl} \)  unit production plus transportation cost ($/cwt) associated with the flow \( x_{ijkl} \); equal to

\[
\frac{c_p}{c_{ij}} \left( \frac{\text{in}}{C_{ij}} + \frac{\text{out}}{C_{ijk}} \right) \quad \text{if transit does not apply}
\]

\[
\frac{c_p}{c_{ij}} + \frac{t}{C_{ijkl}} \quad \text{if transit applies}
\]

where

\( c_p \)  unit production cost

\( c_{ij} \)  unit inbound transportation and associated pipeline inventory costs

\( c_{ijk} \)  unit outbound transportation and associated pipeline inventory costs

\( c_{ijkl} \)  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 \( k \)

\( D_{ij} \) demand (cwt/yr) for commodity \( i \) at customer zone \( j; \)
\( D_{ij} \geq 0 \)

\( \beta_i \) burden factor for commodity \( i \) to be used in calculating
the weighted annual throughput of the distribution centers
(e.g., the units of \( \beta_i \) would be ft\(^3\)/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); \( SL_{ij} \leq SU_{ij} \)

\( VMIN_i \) 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**

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

\( I(x)(b) \) a set composed of the commodity indices corresponding to
bundle \( b \) for customer zone \( x \); thus \( i \in I(x)(b) \) means that
commodity \( i \) is in bundle \( b \) for customer \( x \) zone \( i \); for any
given \( x \), the set \( \cup_{x \in B_i} I(x)(b) \) consists of all commodity
indices.
Optimization Problem

\[
\begin{align*}
\text{Minimize} & \quad \sum_{i,j,k,l} c_{ijkl} x_{ijkl} + \sum_{i,k} \sum_{b \in B_k} \sum_{i \in I_k(b)} V_{ik} D_i y_{kib} \\
& \quad + \sum_k [P L_k u_k + P U_k v_k]
\end{align*}
\]

subject to

\[
\begin{align*}
S_L & \leq \sum_{k,l} x_{ijkl} F S U_{ij} & \text{all } i,j \\
\sum_{i,j,k,l} x_{ijkl} & = D_{il} y_{kib} & \text{all } k \in B_i \text{ and } b \in B_k, \text{ and } i \in I_k(b) \\
\sum_{k} y_{kib} & = 1. & \text{all } k \in B_i \text{ and } b \in B_k \\
y_{kib} & \leq z_k. & \text{all } k \in B_i \text{ and } b \in B_k \\
V_{MIN} z_k - u_k & \leq \sum_{b \in B_k} \sum_{i \in I_k(b)} \beta_i D_i z_k y_{kib} & \text{all } k \\
y_k \text{ and } \bar{u}_k & \geq 0, & \text{all } k \\
y_{kib} & = 0 \text{ or } 1, & \text{all } k \in B_i \text{ and } b \in B_k, \\
z_k & = 0 \text{ or } 1, & \text{all } k \\
x_{ijkl} & \geq 0, & \text{all } i, j, k, l.
\end{align*}
\]

APPENDIX C

The Kuehn and Hamburger Model

Let:

\[ X_{hijk} = \text{the quantity of good } h \text{ shipped from factory } i \text{ via warehouse } j \text{ to customer } k \]

\[ A_{hij} = \text{the per unit transportation cost of skipping good } h \text{ from factory } i \text{ to warehouse } j \]

\[ B_{hjk} = \text{the per unit transportation cost of shipping good } h \text{ from warehouse } j \text{ to customer } k \]

\[ C_{hj}(\sum_{ik} X_{hijk}) = \text{total cost of warehouse operation associated with processing good } h \text{ at warehouse } j \]

\[ D_{hk}(T_{hk}) = \text{explicit or imputed cost due to a delay of } T \text{ time units in delivery of good } h \text{ to customer } k. \text{ If the customer imposes a maximum time limit, } D \text{ becomes infinite when it is reached} \]

\[ F_{j} = \text{planned fixed cost per time period of operating warehouse } j \text{ (not a sunk cost)} \]

\[ S_{hj}(\sum_{ik} X_{hijk}) = \text{semivariable cost of operating warehouse } j \text{ per unit of good } h \text{ processed, including variable handling and administrative costs, storage costs, taxes, interest on investment, pilferage, and so on} \]

\[ Q_{hk} = \text{quantity of good } h \text{ demanded by customer } k \]

\[ W_{j} = \text{capacity of warehouse } j \]

\[ Y_{hi} = \text{capacity of factory } i \text{ to produce good } h \]

\[ Z_{j} = 1 \text{ if } \sum_{hik} X_{hijk} > 0 \text{ and zero otherwise} \]

(that is, \( \sum Z_{j} \) = the number of warehouses used)

The objective function to be minimized is:

\[ f(X) = \sum_{hijk} (A_{hij} + B_{hjk})X_{hijk} + \sum_{i} F_{j}Z_{j} + \]

\[ \sum_{hj} S_{hj}(\sum_{ik} X_{hijk}) + \sum_{hk} D_{hk}(T_{hk}) \]
Subject to the following constraints:

\[ \sum_{ij} x_{hijk} = Q_{hk} \]  
(customer k's demand for product h must be supplied)

\[ \sum_{jk} x_{hijk} \leq Y_{hi} \]  
(factory i's capacity limit on good h cannot be exceeded)

\[ I_j(\sum_{hik} x_{hijk}) \leq W_j \]  
(The capacity of warehouse j cannot be exceeded)

APPENDIX D

The House Model

DEFINE

i  product (each product carries a unique classification rating)

j  market

k  warehouse

l  plant

w  shipment size

m  outbound mode of transportation

n  inbound mode of transportation

D_{k,j,w}  demand for product i at market j in shipment size w

P_{i,l}  production capacity of plant for product i

U_{k}  upper bound on throughput at warehouse k

L_{k}  lower bound on throughput at warehouse k

w_{k}  variable cost per unit throughput at warehouse k

F_{k}  fixed cost of operating warehouse k

T_{i,l,n,k,m,j,w}  cost of transporting product i from plant l over inbound mode n to warehouse k and outbound over mode m to market j in shipment size w

Y_{i,k,j,m,w}  0-1 variable that is 1 if warehouse k is assigned to supply market j with product i in shipment size w over mode m, 0 otherwise

Z_{k}  0-1 variable that is 1 if warehouse k is open, 0 otherwise
APPENDIX D (continued)

Minimize $f(x)$ where:

1. $f(x) = \Sigma_{i,l,k,j} T_{i,l,k,j} + \Sigma_{k} [F_{k}Z_{k} + W_{k}\Sigma_{i,j} D_{i,j}Y_{k,j}]$

   Subject to

2. $\Sigma_{k,j} z_{i,l,k,j} \leq p_{i,l}$ for all $i,j$

3. $\Sigma_{n,k,m} \rho_{i,l,n,k,m,j} = D_{i,j,w}$ for all $i,j,w$

4. $\Sigma_{k,j} \rho_{i,l,n,k,m,j} = 1$ for all $i,k,j,w$

The model assumes no constraints for $p_{i,l}$, $L_{k}$ or $U_{k}$. Note also that multiple inbound modes are permitted. This may be constrained through the introduction of an additional 0-1 variable to restricting the summation over $n$ to be 1. In finding a solution to $f(x)$ the model either assigns markets to warehouses based on the outbound portion of the transportation cost by solving

$$\min \Sigma_{k,m} T_{i,,..,k,m,j,w}$$

for all $i,j,w$

or finds the least variable cost plant to market link by solving

$$\min \Sigma_{l,n,k,m} [T_{l,n,k,m,i,l,n,k,m,j,w} + w_{k}$$

for all $i,k,w$

Once one of these two linking patterns has been determined $f(x)$ can be computed.

APPENDIX E

Simulation Model Formulation

Let

\[ \begin{align*}
  i & \quad \text{product} \\
  j & \quad \text{market} \\
  k & \quad \text{warehouse} \\
  \lambda & \quad \text{plant} \\
  n_i & \quad \text{number of annual orders for product } i \\
  i_0 & \quad \text{number of orders in a consolidated shipment} \\
  p & \quad \text{pooling point} \\
  u & \quad \text{system structure:} \\
   & \quad 1 = \text{ship from plant - no consolidation} \\
   & \quad \quad (0 \text{ holding days}) \\
   & \quad 2 = \text{ship from plant - consolidation} \\
   & \quad \quad (1 \text{ holding day}) \\
   & \quad 3 = \text{ship from plant - consolidation} \\
   & \quad \quad (4 \text{ holding days}) \\
   & \quad 4 = \text{ship from warehouse - no consolidation} \\
   & \quad \quad (0 \text{ holding days}) \\
   & \quad 5 = \text{ship from warehouse - consolidation} \\
   & \quad \quad (1 \text{ holding day}) \\
   & \quad 6 = \text{ship from warehouse - consolidation} \\
   & \quad \quad (4 \text{ holding days}) \\
  w & \quad \text{shipment size (cwt)} \\
  W & \quad \text{consolidated shipment size (} \sum_{i=1}^{I} X_{ij} \text{)} \\
  C_{iu} & \quad \text{cost of a shipment of product } i \text{ using system structure } u \\
  D_{ij} & \quad \text{annual demand for product } i \text{ at market } j \\
  I_{iu} & \quad \text{Inventory carrying cost and cycle stock costs (} \$/\text{cwt) for} \\
   & \quad \text{system structure } u \\
  S_k & \quad \text{storage costs per hundred weight for warehouse } k \text{ (} \$/\text{cwt) } \\
  T_{Cu} & \quad \text{Total annual costs under system structure } u \\
  TL_i & \quad \text{truckload rate for product } i \text{ (} \$/\text{cwt) between two points} \\
  T_{iw} & \quad \text{LTL rate for product } i \text{ (} \$/\text{cwt) in shipment size } w \text{ between two points, e.g.,} \ k, \ k_j, \ \lambda_p, \ \lambda_j \\
  V_k & \quad \text{handling cost (} \$/\text{cwt) less carrying cost at warehouse } k \\
  V_p & \quad \text{handling costs at pooling point } p \text{ (} \$/\text{cwt) } \\
  X_{ij} & \quad \text{individual order for product } i \text{ by market } j \text{ (cwt)}
\end{align*} \]
APPENDIX E (continued)

\( Y_{ijkm} = 0-1 \) variable to indicate whether warehouse \( k \) (or pooling point \( p \)) is assigned to supply market \( j \) with product \( i \) in shipment size \( w \).

\( Z_k = 0-1 \) variable to indicate whether warehouse \( k \) (or pooling point \( p \)) is open.

Individual order costs of system structure \( u \) (Note: \( w = x_{ij}, \ W = \sum_{io} x_{ij} \))

\( u = 1: \) ship from plant - no consolidation

\[ C_{i1} = T_{i1jw}(X_{ij}) + I_{i1}(X_{ij}) \]

\( u = 2 \) or \( 3: \) ship from plant - consolidation

\[ C_{i2} = \frac{X_{ij}}{\sum_{io} X_{ij}} \left[ T_{i2pw}(\sum_{io} X_{ij}) + V_p Y_{ijpm}(\sum_{io} X_{ij}) \right] + I_{i2}(X_{ij}) + T_{ipjw}(X_{ij}) \]

\( u = 4: \) ship from warehouse - no consolidation

\[ C_{i3} = T_{i3kw}(X_{ij}) + T_{ikjw}(X_{ij}) + Y_{ikjm} Z_k \]

\( (V_k + S_k)(X_{ij}) + I_{i3}(X_{ij}) \)

\( u = 5 \) or \( 6: \) ship from warehouse - consolidation

\[ C_{i4} = \frac{X_{ij}}{\sum_{io} X_{ij}} \left[ T_{i4kw}(\sum_{io} X_{ij}) + V_k Z_k Y_{ijkm}(\sum_{io} X_{ij}) \right] + I_{i4}(X_{ij}) + (T_{ikjw} + T_{ijjw})(X_{ij}) \]

Note: \( T_{ijjw} \) is local delivery cost if a shipment is pooled to the demand point. If the shipment is not pooled, \( T_{ijjw} = 0. \)
APPENDIX F
ASSUMPTIONS OF SIMULATION MODEL

ASSUMPTIONS UNDERLYING THE GENERATION OF POOLING POINT AND WAREHOUSE CONFIGURATIONS AND SIMULATIONS AS CURRENTLY IN COMPUTER PROGRAMS

Key Words:

- Configuration: network of warehouses or pooling points used to distribute goods to demand points. Khumawala program generates each configuration for different distribution system structures.

- Simulation: used here to refer only to simulation of 250 days of orders.

Objectives:

1. Investigate the influence of the following variables on the decision to use consolidation and/or warehouse distribution structures: total annual volume, mean order weight, geographic distribution of demand, plant location, and product classes.

2. Predict which system structure is preferable for specific values of the variables identified.

LOGISTICS ASSUMPTIONS

I. Determination of Warehouse or Pooling Point Configurations

A. Input data for Khumawala program

1. Fixed warehouse costs = 50000 square feet * annual cost per square foot.

2. Warehouse variable costs
   a. Carrying Costs - 30% of product valued at $4 per pound
      1) Annual carrying costs per hundredweight (cwt) = CCAN= .3 * ($400/cwt) = $120
         Share of annual carrying costs assuming eight turns of average inventory = CCAN/TURNS.
         TURNS = 8,

      2) Increment for decentralized stock (AIMCR).
         Based on Maister's "Square Root Law" the increase in carrying costs due to decentralization is the sum of the square roots of the percentages of total
annual volume flowing through each warehouse. For the Khumawala program, AINCR = \sqrt{\text{number of potential locations}/2}

The value of AINCR used in the simulations is calculated and output from the Khumawala program.

Since the square root law also has application to safety stocks, AINCR is multiplied by 1.1 to include not only increases in average stock but also increases in safety stocks assuming a ten percent safety stock level. Maister's square root law assumes an economic order quantity based inventory policy. If such a policy is not used, then AINCR should be used only for increases in safety stock to cover lead time in the simulations.

3) Total carrying costs input into the Khumawala program = annual carrying costs * increase in average inventory and safety stock * order weight/number of turnovers per year = CCAN*AINCR*1.1*(MOW/100)/TURNS.

b. Other variable costs which are also included in the simulation as the variable WHSVC.

1) Clerical costs
   a) Time: 12 minutes to process order * 1 orders = .2 hr

   Assume incoming and outgoing orders must each be processed. Since inbound orders are truckloads, the inbound order processing time is = (order weight/40000 pounds) * .2 hr. Total order processing time is .2 + inbound time.

   b) time*hourly clerical cost = clerical cost

2) Labor
   a) If order weight is greater than or equal to pallet weight of 1500 pounds, then pick, pack, and load time is 10000 #/hour. If order weight is less than pallet weight, then labor time = 1.7 order weight but never less than .1 hr or 6 minutes.

   b) Labor time*fully burdened labor rate = labor cost

3) Total WHSVC per order = clerical cost + labor cost.

3. Transportation costs for pooling point or warehouses
   a. For each demand point, find the cost to ship a mean order weight shipment to the demand point through each potential warehouse/pooling point location. The exception to this formulation is
that for consolidation from warehouses, order weight is increased by 2.5 times to account for larger shipments sizes between the warehouse and demand point. 2.5 is an average of one and four days increased shipping volumes for the two holding strategies.

Truckload rates are used for transportation costs to the warehouse locations. Annual transportation costs = costs + truckload cost to warehouse*(number of truckloads per year) + cost for mean order weight from warehouse to demand point*(number of mean order weight shipments per year).

b. In the pilot study, the average pooled shipment weight ranged from 5400 pounds for consolidation from warehouses to 80,000 pounds for pooled shipments from plants. The average pooled shipment from plants varied approximately with mean order weight and annual orders shipped. Therefore, transportation rates to a pooling point are based on total annual hundredweight through the system. Initial analysis suggested the sum of mean order weight in hundredweight and the number of annual orders in thousands is a good approximation of average pooled shipment weight. The rate for this value was used for shipment from the plant to the pooling point.

B. Khumawala Configuration generation program
The Khumawala program is a linear programming algorithm with no side constraints which trades off fixed and variable costs. Thus, there are only two values input for each demand point-potential supply location pair.

1. Adjustments to program
a. To keep the program from aborting when encountering zero demand at some demand points, the variable INIT was created. If INIT=1 do not abort if KTR=0 after statement 1300. Set INIT=0 after all data checked once.

b. Require all pooling points to have minimum volume of 5000 pounds every 4 days. This minimum is set to cover both 1 and 4 holding days but favors 4 days.

c. Require warehouses to be at all plant locations. This requirement is not made of pooling points.

2. Output from Khumawala program
a. Configuration of warehouses or pooling points and which demand points each serves.
   A different pooling point configuration was generated for each plant in the multi-plant case.

b. Volume through each pooling point/warehouse
c. AIMCR - increment in carrying costs due to use of warehouses.

II. Simulation

A. Number of orders generated per day
   1. Total annual orders are divided among the demand points in proportion to geographic demand by population or by manufacturers' value added. This amount is again divided if more than one product is demanded. In the current simulation either one product class accounts for total demand or three product classes have equal demand.

   2. The number of orders for a specific product for a specific demand point for a specific day is a poisson function of the volume determined in 1. above.

   3. Each product is simulated separately for each day and data are cumulated every fifty days.

B. Order weight
   Order weight is a random variable from a truncated normal distribution with a mean equal to one level of order weight .8 and a standard deviation equal to the mean.

C. Shipment algorithm
   1. Orders are held up to a maximum of 0, 1, or 4 days. In the no consolidation structures, orders are shipped the day they are received. In Masters' "consolidation algorithm," orders shipped directly to customers from plants are not held or consolidated with other orders.

   2. A consolidated order is not held the maximum holding time if a) there is an older order for the same pooling point, or demand point in the case of consolidation from warehouses, that exceeds the holding time limit or b) if the consolidated shipment reaches the minimum release weight of 40000 pounds.

D. Transportation Costs (DCOSTS)
   1. Each record in the rate file contains weight breaks for a specific product class for a specific origin-destination pair. A pointer system (HVID) is used to locate specific records. The class 40 rate has been added at the end of the record when available and is used for truckload weights of 40000 pounds or more.

   2. Search Algorithm
      a. The weight break categories are sequentially checked to determine whether the order weight is less than the weight
break. If this occurs the actual weight is multiplied by the associated charge. The maximum of the minimum charge and this value is chosen as DCOSTS.

Checks are included for reaching the incentive weight break of 999. In that case, the algorithm checks whether a class 40 rate is available and if so whether the shipment weight exceeds 40000 pounds. If both conditions exist, the class 40 charge is used.

b. The weight break selected in 2a is then multiplied by the charge associated with the next highest weight break to determine if a lower cost occurs by declaring at a higher weight category, known as over-declaring. The minimum of DCOSTS and this value becomes DCOSTS.

If weight break 999 is encountered when checking for over-declaring, the class 40 weight break of 400 cwt is used if available.

If the next charge used in checking for over-declaring has an associated weight break of 999, then the class 40 cost is also checked because that cost may be lower than the cost using the 999 charge. The minimum of these costs becomes DCOSTS.

c. Break bulk charge is $.41 per hundredweight if shipment passes through a pooling point.

d. UPS rates were not included for small order weights. Only interstate common carrier rates were used. New England rates 3, 4 and 5 were used for classes 100, 77.5, and 60 respectively.

No costs are calculated if the origin and destination are the same or rates are not available for a specific origin-destination pair. The latter case did not arise.

E. Carrying costs per hundredweight

1. Share of annual carrying costs = CCAN/TURNS = $120/8 = $15

2. Holding and in-transit carrying costs = number of days the order is held * number of days in transit) *
   (carrying costs per day). Carrying costs per day =
   CCAN/365 days = $.329

3. Increment in carrying costs due to use of warehouses compared with centralized storage = (AINCB-1) * safety stock. Safety stock in system = square root of lead time * (standard deviation of daily usage).
   Lead time is the first leg time from plant to warehouse (PLT). Daily usage is a function of the number of orders received per day (TAO/250) and the average weight per order (MOW). Thus, the standard deviation of demand is a convolution of two
distributions = sqrt((TAO/250) + (HOW)**2) + (HOW)**2 * (TAO/250).

F. Order costs for each system structure

1. Direct from plant—no consolidation
Order costs consist of a) transportation costs and b) carrying costs including during transit time.

The increment in carrying costs is added because of cycle inventory for goods in transit. The increment is equal to the number of days in transit * carrying costs per day * order weight in hundredweight.

2. Consolidated from plant
Order costs consist of a) share of pooled shipment transportation costs to pooling point, b) transportation costs from pooling point to demand point, c) break bulk charge of $ .41 per cwt at the pooling point, and d) carrying costs including an increment for holding the order and transit time.

An increment in carrying costs is assumed because for each day an order is held inventory is not reduced and costs are incurred by slower turnover of goods and capital. The increment is daily carrying charge*number of days the order was held and in transit *order weight in cwt.

3. Direct from warehouse—no consolidation
Order costs= a) share of truckload transportation costs to the warehouse, b) transportation costs from the warehouse to demand point, c) variable costs WHSVC described in IA3b, d) storage costs at the warehouse, and e) carrying costs including transit time carrying costs and increased safety stock.

Storage costs are calculated as storage per square foot* (4.5/TURNS) * order weight /(1500).

The storage cost formula is based on the following assumptions:

- 18 square feet floor space for one pallet
- stack 4 pallets high in warehouse
- 1500 pounds per pallet

Thus, 4.5 square feet of space are required to store one pallet for one year. Divide by the number of stock turns and pallet weight to obtain charge for an individual order.

4. Consolidated from Warehouse
Order costs= a) share of truckload transportation costs to warehouse, b) share of pooled shipment transportation costs to demand point + local delivery, c) variable costs WHSVC, d) increment in carrying costs for holding and transit times and safety stock, and e) storage costs.

G. Transit time algorithm
Transit time is assumed to be a gamma function of both
order weight and distance. Masters' function permitted a maximum distance of 3000 miles which is the limit of Piercey data upon which the function is based. The maximum weight was 10000 pounds. The algorithm returns a random variable constrained to be at least one day and no more than 25 days.

Two gamma generating functions were investigated because the first encountered underflow conditions periodically. Both functions exhibited this characteristic. A standard fixup occurs of substituting zero for the underflow value. The researcher introduced a check on the underflow which reduced the number of underflows but did not eliminate them. Since the total number of underflows in any one run of all four systems was approximately 500 for between 300,000 and 1,500,000 orders generated, the advice given the research was to permit the standard fixup to handle the situation. The check introduced by the researcher is still in the program and may be removed before the program is run by others.

1. Transit times for consolidated shipments
   In addition to the transit time based on weight and distance, more time is added for the number of days the order is held before shipment. When pooling points are involved, a break bulk time of one day is added to the total for handling time at the pooling point.

2. Transit times from warehouses
   No transit time from the plants to the warehouse is included for the system structures using warehouses although the value is calculated for assessing increases in safety stock and carrying costs. Backorders are not permitted.

3. Unconsolidated orders
   Only the gamma transit time is included.
APPENDIX G

LISTING OF COMPUTER PROGRAM

THE FOLLOWING PROGRAM IS DESIGNED TO OFFER CONFIGURATIONS AND SIMULATE 240 DAYS BUSINESS FOR SIX DIFFERENT SYSTEM STRUCTURES.
CURRENT CONSTRAINTS ON PROGRAM ARE:
NUMBER OF PRODUCTS = 3
NUMBER OF PLANTS = 3
NUMBER OF WAREHOUSES = 100
NUMBER OF CUSTOMERS = 190
THE VARIABLES USED IN THIS PROGRAM ARE LISTED BELOW:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE</td>
<td>Age of Oldest Under for Customer 1 Product 13.5</td>
</tr>
<tr>
<td>QNT100000</td>
<td>Contains Int for Consulation Simulations</td>
</tr>
<tr>
<td>ANNU1991</td>
<td>Annual Order Wgt, All Shipts for Direct Plant</td>
</tr>
<tr>
<td>APN1</td>
<td>Annual Pooling Wgt, All Shipts for Direct Plant</td>
</tr>
<tr>
<td>MAX</td>
<td>Maximum Break Bulk Charge</td>
</tr>
<tr>
<td>CSAM</td>
<td>Annual Carrying Cost Percentage of List Price</td>
</tr>
<tr>
<td>CCNM</td>
<td>Annual CC in Dollars (CCM/1000)</td>
</tr>
<tr>
<td>CCNAY</td>
<td>Daily CC in Dollars (CCM/1000)</td>
</tr>
<tr>
<td>CPTIV</td>
<td>List Price of Product in Dollars/Unit</td>
</tr>
<tr>
<td>FLG</td>
<td>First Leg Cost</td>
</tr>
<tr>
<td>FLT</td>
<td>First Leg Time</td>
</tr>
<tr>
<td>FRLANK</td>
<td>First Empty Position in IHQ</td>
</tr>
<tr>
<td>FYDAY</td>
<td>Day Specific Order Generated</td>
</tr>
<tr>
<td>FYDIST100</td>
<td>Distance Map 1</td>
</tr>
<tr>
<td>FCP1198</td>
<td>Location of First Order for Customer 1</td>
</tr>
<tr>
<td>LCP1198</td>
<td>Each Col is for One Product if 2nd Dimension</td>
</tr>
<tr>
<td>FCP1501</td>
<td>Fixed Contractual Warehouse Program</td>
</tr>
<tr>
<td>FFMC1000</td>
<td>Fixed Warehouse Costs</td>
</tr>
<tr>
<td>FPR100000</td>
<td>Holds Order Strings, Cols as follows:</td>
</tr>
<tr>
<td>T-NGI</td>
<td>First Order</td>
</tr>
<tr>
<td>B-NGI</td>
<td>Second Order Placed</td>
</tr>
<tr>
<td>3-LOC</td>
<td>Location of Next Order for Customer 1</td>
</tr>
<tr>
<td>4-NGI</td>
<td>Which Product Order Is For</td>
</tr>
<tr>
<td>TCX</td>
<td>Total Variable Pooling Costs Incl Transp</td>
</tr>
<tr>
<td>TOTTW150</td>
<td>Total Variable Warehousing Costs Incl Transp</td>
</tr>
<tr>
<td>TWP1981</td>
<td>Wgt of T Pooled Shipment</td>
</tr>
<tr>
<td>TWP1981</td>
<td>Wgt of T Pooled Shipment</td>
</tr>
<tr>
<td>BATT100000</td>
<td>Contains Up to Ten Weight Breaks Per Record</td>
</tr>
<tr>
<td>TWS125000</td>
<td>Contains Weight Breaks Per Record</td>
</tr>
<tr>
<td>ISGSE</td>
<td>Number Indicates Location of Plants In</td>
</tr>
<tr>
<td>ISGSNZ</td>
<td>ZIP Code Order In List of Potential Plants In</td>
</tr>
<tr>
<td>ISGZS</td>
<td>ZIP Codes of Plants Used to Get ISGSE Values</td>
</tr>
<tr>
<td></td>
<td>By Orig By Other By Product</td>
</tr>
<tr>
<td>NOTES</td>
<td>Dimension of INATE Must Be Changed If NC X NW GT 20000</td>
</tr>
<tr>
<td>TWVAL150</td>
<td>Fixed and Variable Warehouse Costs</td>
</tr>
<tr>
<td>TWCS1990</td>
<td>Warehouse Consensus Program</td>
</tr>
<tr>
<td>INU1501</td>
<td>Used To Get Wgt Location Within Customer</td>
</tr>
<tr>
<td>INAD150</td>
<td>Printer To Rate File, Extile 13 Contains the</td>
</tr>
<tr>
<td>INAT</td>
<td>Location in the Rate File for Shipmen</td>
</tr>
<tr>
<td>INAT1</td>
<td>From 1 to J</td>
</tr>
<tr>
<td>INUT</td>
<td>Wgt of Specific Order</td>
</tr>
<tr>
<td>INAT198</td>
<td>Location Assigned to Handle Customer 1's Orders</td>
</tr>
<tr>
<td>INAT198</td>
<td>Entry Is Rank Number in Zip Code Sequence</td>
</tr>
<tr>
<td>INAT198</td>
<td>3-Digit Zip Codes for Customer Zones</td>
</tr>
<tr>
<td>INAT198</td>
<td>3-Digit Zip Codes for Warehouse Locations</td>
</tr>
<tr>
<td>ICNDR1</td>
<td>Value Determines Which System Structure Being Executed</td>
</tr>
<tr>
<td>LPP150</td>
<td>Contains the Rank Number of Locations in Zip Seq</td>
</tr>
<tr>
<td>ICN</td>
<td>In Configuration Output By Cultural Program</td>
</tr>
<tr>
<td>LPOD14</td>
<td>Product Classes of Products in This Run</td>
</tr>
<tr>
<td>NW</td>
<td>Maximum Holding Days for Consulation</td>
</tr>
<tr>
<td>WCHG120000</td>
<td>Minimum Charge for Shipmen From 1 to J</td>
</tr>
<tr>
<td>MOW</td>
<td>Mean Order Weight in Pounds</td>
</tr>
</tbody>
</table>
| NMG     | Max Release Wgt in Pounds (TWT)

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAME159</td>
<td>Names of Markets (Customer Zones)</td>
</tr>
<tr>
<td>NAMT199</td>
<td>Number of Annual Orders From Customer 1</td>
</tr>
<tr>
<td>NUMN</td>
<td>Number of Customers (H tmALL)</td>
</tr>
</tbody>
</table>
C ASSUME CARRYING COSTS OF 30% (CC).  
C PRODUCT IS VALUED AT $400 PER CAT.  
NOAD=250  
CCST=3  
CWT=400  
CCAN+CWT*CCST  
CDAY=CCAN/165.  
C WRITE(11,667) CC,CWT,CCAN,CDAY  
667 FORMAT(H11.6D7.)  
4F13.6)  
ECODE=1  
NPLR(1,1)=1  
NPLR(1,2)=0  
NPLR(1,3)=0  
NPLR(2,1)=0  
NPLR(2,2)=1  
NPLR(2,3)=0  
NPLR(3,1)=0  
NPLR(3,2)=0  
NPLR(3,3)=1  
C LTH IS THE LENGTH OF THE RATE FILE  
LSTL=10407  
NPROD=3  
NLATS=3  
NDP=154  
NPCC=40  
PCP=NPCC  
NP=20  
ITFLMT=40000  
TLW=40000  
MRW=TLW  
TPPOP=0  
C TURNS=8.  
C READ DISTANCES AND RATES  
C NOTE: IDIST,MINCHG, IRATE ARE ALL INTEGER#2  
DO 6 1=1,NPCP  
6 READ(12,790) (IDIST(1,J),J=1,NDP)  
C WRITE(11,750) (IDIST(1,J),J=1,NDP),I=1,NPCP)  
750 FORMAT(184)  
DO 8 I=1,LRLTH  
REO(1,761) MINCHG(I), (IRATE(I,XX),XXX=1,8)  
8 CONTINUE  
C WRITE(11,761) MINCHG(I), (IRATE(I,XX),XXX=1,8)  
760 FORMAT(15X,9(I3,1(4)))  
761 FORMAT(8X,9(I3,1(4)))  
DO 10 1=1,NDP  
C  
C READ IN MARKET INFORMATION  
C NOTE: ZIP, IPOP ARE ALL INTEGER#2  
READ(12,401) (ZIP(I),I=1,4),IPOP(I)  
IPDP=TPPOP(IPOP(I))  
DO 11 LL=1,NPROD  
THWLL(LL)=0  
1400(I,LL)=0  
11 IF(01,LL)=0
10 CONTINUE
C WRITE(1,801) (F('I',J),J=1,A),(P('I',J))
C READ WAREHOUSE LOCATION POINTERS FOR CUSTOMER LIST
    READ(3,765) (IWAY(J),J=1,NP)
765 FORMAT(I1)
C READ IN WQD MATRIX
    READ(3,766) (IWAY(J),J=1,NP)
    DO 50 I=1,NP
        READ(3,765) (IWAY(I),J=1,A)
50 CONTINUE
C READ IN FIXED AND VARIABLE WAREHOUSE COSTS
C WRITE(1,766) (IWAY(I),J=1,A)
C DO 700 I=1,NP
    DO 300 J=1,A
        DO 200 K=1,3
            NAD(J)=NAD(J)+1
            NAD(J)=NAD(J)+1
        END DO
        C WRITE(1,770) (F('I',J),P('I',J), AWD(J), NAD(J))
    C WRITE(1,771) (F('I',J), AWD(J), NAD(J))
    700 FORMAT(I1,15F1.5,15F1.5)
C DO 20 J=1,NP
20 CONTINUE
C WRITE(1,771) ((F('I',J), J=1,NP),J=1,1)
CALL GENPOL
220 DO 205 LLL=1,1,PLANT
220 DO 203 I = 1,NPL
205 CONTINUE
CALL SPLP
GO TO 1000,2000,10000,10001,JCODE
C
C SHIP DIRECT FROM PLANTS
C
1000 JSFED=745.44
1000 JSFED=456.19
CALL RSTART(SEED, JSEED)
DO 1001 I = 1,100
1001 Y=UNI(I)
WFLW=0.
TWVHCW=0.
TWHTR=0.
TCC=0.
NO=0
MMT=0
APW=0.
NCO=0
NCOC=0
N=0
SOC=0.
SSOC=0.
R=0
RASSOC=0.
NASSOC=0.
SDI=0.
SSDI=0.
RSSDI=0.
SSDII=0.
S=0.
SSS=0.
RSSS=0.
TORC=0.
NPN=0
WRITE(9,5561) JCODE, SMT, MOW, TAO, (SIRCS(I), I=1,NPROD).
*(LPRD(I,L))=1,1,NPROD)
WRITE(11,5561) JCODE, SMT, MOW, TAO, (SIRCS(I), I=1,NPROD).
*(LPRD(I,L))=1,1,NPROD)
DO 1100 IDAY=1,NDAY
DO 1100 LLL=1,NPROD
DO 1100 LLL=1,NPROD
IF (LPRD(I,L), Q=0) GO TO 1100
ISRC=ISRC(I)
DO 1120 J = 1,NPROD
AM=AMNT(I,J)
NOR=NPSX(J)
IF (NOR, Q=0) GO TO 1200
DO 1120 J = 1,NOR
1110 IF (M = NRM+1,MOW)
WRITE(11,779) NOR, IW, MOW
C
WRITE(I11,779) NOR, IW, MOW
778 FORMATT(1210,110)
1M=IDIST(I,IRCS)
NCD=NCD+1
NT=TIMS(SINT, 1)
TRC=TCSTIME(TSIFS, TSIRCS, I, LLC)
CC=(CCDAY*) * CCAN/TURNS) * IMF/100.
C
VOL(I)=VOLUM(I)*1.
QC=TRC+CC
TC=TCF+CC

00002730
00002740
00002750
00002760
00002770
00002780
00002790
00002800
00002810
00002820
00002830
00002840
00002850
00002860
00002870
00002880
00002890
00002900
00002910
00002920
00002930
00002940
00002950
00002960
00002970
00002980
00002990
00003000
00003010
00003020
00003030
00003040
00003050
00003060
00003070
00003080
00003090
00003100
00003110
00003120
00003130
00003140
00003150
00003160
00003170
00003180
00003190
00003200
00003210
00003220
00003230
00003240
00003250
00003260
00003270
00003280
C
00003290
00003300
00003310
00003320
00003330
00003340
00003350
00003360
00003370
00003380
00003390
00003400
660 FORMAT(1H,2,15,2,110,5F10.2,2,110)
C IF(MOD(DAY,7)+DOY.1,HA.1) GO TO 1120
C WRITE(6,668) ISRC,Y,INT,THC,CC,NC,DT,SSW,SMW,LL
1120 CONTINUE
1200 CONTINUE
1800 CONTINUE
IF(MONTH>DAY,501,503) CALL TOTAL
1700 CONTINUE
GO TO 5000
C CONSOLIDATION FROM PLANTS ONLY
C 2000 CONTINUE
DO 2110 K=1,4,3
C ON 2105 I=1,NRP
C2105 VOL(1)=0.
MM=K
C WRITE(6,556) JCODE,MM,MT,MW,TAO,11SRES(1),I,1,NPROD)
CALL SIMUL
2110 CONTINUE
GO TO 5000
C
C C SHIP DIRECT FROM WAREHOUSES ONLY
3000 CONTINUE
WRITE(6,556) JCODE,MT,MW,TAO,11SRES(1),I,1,NPROD)
* (NPROD(1),LL=1,NPROD)
WRITE(6,556) JCODE,MT,MW,TAO,11SRES(1),I,1,NPROD)
* (NPROD(1),LL=1,NPROD)
556 FORMAT(5X,JCODE,L9,MT,MW,TAO,11SRES(1),I,1,NPROD)
** (SRES(1),315,"CLASS",315,"PENG DEM= WFG W 庸")
SSAV=I
** IF(MYM,F0.1) SSAT=I
3100 DO 2700 NDAY=1,NDAY
DO 3800 LL=1,NPROD
IF(NPROD(L),F0.0) GO TO 3800
11SRC=1596(1)
DO 3220 J=1,NDP
   XW(1)WDO(I,L,L)LNL
   NORD=NPSN(I,1,1)
   IF (NORD.EQ.0) GO TO 3220
DO 3220 J=1,NORD
3110 IWT=NM,1,1,1
   IF (IWT.LT.1) GO TO 3110
   IWHSE=I2B(I,L,L,L)
   IWHSE=IWHSE IWHSE
   IWHSE=IWHSE IWHSE
   FWT=ITIMES(I,1,1,1,1,1)
   WFT=WFT*FWT
   FLC=0.
   IF (ISRC.EQ.IWHSE) GO TO 3112
   FL E=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
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   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
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   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
   SLC=NCOSTS(I1,1,1,1,1,1,1,1,1)
C TIMES=0, IF IM=0
  IFF(IM,GT.0) GO TO 10
  TIMES=0
  RETURN
10 XM=1+1/100.
  IFF(XM,GT.10,1,XM=100.,
  XD=1,0
  IFF(XM,GT.3000,1,XD=3000.)
C DENOMINATORS FOR XM CHANGED FROM MASTERS PROG
  XM=2.0-(14100.1+11.4*X0)/10000.-(14*XD*XW)/700000.0
  XS=2.0-(115*XW)/1000.-(11.4*X0)/70000.-(115*XW)/700000.0
100 FORMAT(5X,ITIME&1,4F10,2)
  TIMES=GAMMA(XM,X50)
C WRITE(11,799) TIMES,IC,M,IM,XTM,X50
799 FORMAT(1H,",ITIME=",F12.4,"T110,2F15.6)
  RETURN
END
C
C POISSON FUNCTION FOR NUMBER OF ORDERS PER DAY
FUNCTION NPSN(XMU)
  NPSN=0
  IFF(XMU,LT.20.0) GO TO 50
  MU=XMU
  NPSN=NPSN+1
  RETURN
50 Z=EXP1(-XMU)
  X=1.0
60 R=UNI(101)
  X=X*R
C WRITE(11,777) XMU,Z,R,X,NPSN
777 FORMAT(1H,",4F12.4,110)
  IF(XLT.2) RETURN
  NPSN=NPSN+1
  GO TO 60
END
C RANDOM VARIABLE FROM DISTRIBUTION WITH MEAN=STD. DEV.
C FUNCTION NRMLM1
C CHANGING MASTERS PROGRAM TO REDUCE CODE BY 20%
2M=.8MM
10 MM=UNIT(101)
  RMM=UNIT(101)
  ZM=-2.0*ALOG10(RA)*0.5*COS(6.2837*RH)
C ZM=M1
C NRMLM1=2 SORT (ZM)+MM
C HAVE CHANGED MM TO ZM BELOW
  NRML=ZM+ZM
  RVL=0
  NRML=MAXO(NRML,NRML)
  IF(NRML.GT.0) GO TO 10
C WRITE(11,777) MM,RA,RR,Z,NRML
777 FORMAT(1H,",110,3F10.6,110)
  RETURN
END
C GAMMA FUNCTION FOR TRAVEL TIME
C
FUNCTION GAMXMU(SIGMA)
  BETAM=SIGMA/XMU
  ALPHAM=XMU/BETAM
  K=ALPHA
  F=K
  G=K
  IF(K) 10,10,10
10 PRD=1.0
  GO TO 20
  I=1
  K
10 MM=UNIT(101)
20 PRD=PRD*MM
  IF(PRDL.E.10**(-75)) PRD=0.0
  GOTO 10
558 FORMAT* (LJL, 4X, 415)
   IBLANK = NBLANK
   GO TO 120
118 NHF = IFOIL, LL1
   NBLANK = IFOIL (IBLANK, 1)
   IBLANK = IBLANK - 3 - NHF
   IFOIL, LL1 = IBLANK
C \* WRITE (II, 559) (FJLIL, LL1, I, IBLANK, NBLANK, 000)
559 FORMAT* (II, 515)
   IBLANK = NBLANK
   CONTINUE
   120 CONTINUE
   200 CONTINUE
2800 CONTINUE
C \* SHIP FROM PLANT WAREHOUSES TO CUSTOMERS SERVED BY WHSE-NO IN LD
   00009000
   DO 2810 LL1 = 1, NPPR
   IF (PR1POWELL, LL1, 0, 0) GO TO 2810
   ISRC = ISRCFILL (LL1)
   LL1 = LL1
   IF (400, LL1, 0) GO TO 2810
   IF (1000, I, 0, 0) GO TO 400
400 INDEX = IF (1, LL1)
   IF (INDEX, EQ, 0) GO TO 400
   IM = INDEX (I)
   DT = DTINSF (IM, IM)
   DT = DTINS (1)
   DT = DTINS (2)
   DT = DTINS (3)
   DT = DTINS (4)
   DT = DTINS (5)
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   DT = DTINS (236)
C EXECUTE ONE VALUE TO FILL EACH ENTRY IN AN NC X NW MATRIX.
C EACH ELEMENT IS = 1.0 COST / CWT FOR 1ST LEG + VARIABLE
C WAREHOUSING COSTS / CWT + 2ND LEG TRANSPORTATION COST / CWT
C X TOTAL CWT DEMAND AT EACH CUSTOMER LOCATION.
C SECOND LEG TRANSPORTATION COSTS ARE FIGURED FOR MEAN ORDER SIZE.
C IF MORE THAN ONE PRODUCT, EACH is THE SUM OF
C PRODUCT COSTS AT THE CUSTOMER LOCATION.
C INPUT CONSISTS OF:
C PART MATRIX (NC X NW X #ATE BREAKDOWNS X # PRODUCTS)
C VARIABLE WAREHOUSE COSTS (NW X NUMBER OF PRODUCTS)
C DEMAND (NC)
C WHERE NC = NUMBER OF CUSTOMER LOCATIONS, NW = POTENTIAL
C WAREHOUSE LOCATIONS.
C LPROM CONTAINS THE PRODUCT NUMBERS IF ONLY ONE PRODUCT.
C PUT 0 IN REMAINING VECTOR.
C RATE CONTAINS THE OPTIMAL PROPORTION OF DEMAND FOR EACH PRODUCT.
C TOTAL OF NUMBERS IN RATE SHOULD == 1.
C ISRC CONTAINS THE SOURCE PLANT FOR EACH PRODUCT.
C WT = MEAN ORDER WEIGHT IN POUNDS
C
C ORDN NUMBER OF ANNUAL ORDERS
ORD=TAU
ID=(OMLTAU/1000.0)*1000.
ITFJON(5,4) GO IN 20
WT=MINW/2.5
ORD=100/2.5
C DIFFERENT VARIANTS EXISTS PER PRODUCT?
C
20 CONTINUE
C INCLUDE PLANT LOCAL DELIVERY FOR CONFIG GENERATION ONLY
C 2D IUTL=1
C WRITE(11,500) 1117
C
C CREDIT ENTRIES TO INOUT AND INOUT MATRICES,
DO 70 I=1,NC
    PRC=TOPP(I)/TOPP
    DO 60 J=1,NW
        DO 50 JJ=1,NC
            25 LOUT(J,J,J,J)=0
            INOUT(J,J)=0
            INOUT(J,J,J)=JJ
            IF (LOUT(J,J,J,J).GE.60) GO TO 60
            IF (INOUT(J,J,J,J).GE.60) GO TO 60
C CHECK WHETHER RATES FROM J TO I ARE IN FILE
    IF (LWXDI(I,J,J,J).GE.0) THEN
        IOUTP(J,J,J)=I
        GO TO 60
        IOUT(J,J,J)=J
        TEN=0
        IF (IOUTP(J,J,J)=0) THEN
            IF (IOUT(J,J,J).EQ.0) THEN
                ITMV=ITMV+I
                IF (ITMV.EQ.0) THEN
                    ITMV=0
                    ITMV=ITMV+I
            ELSE
                ITMV=ITMV+I
            END IF
        ELSE
            IF (IOUTP(J,J,J).EQ.0) THEN
                ITMV=ITMV+J
                IF (ITMV.EQ.0) THEN
                    ITMV=0
                    ITMV=ITMV+J
                ELSE
                    ITMV=ITMV+J
                END IF
            ELSE
                IOUT(J,J,J)=ITMV
                ITMV=ITMV+J
            END IF
        END IF
        IF (IOUT(J,J,J).EQ.0) THEN
            IF (IOUTP(J,J,J)=0) THEN
                ITMV=ITMV+I
                IF (ITMV.EQ.0) THEN
                    ITMV=0
                    ITMV=ITMV+I
                ELSE
                    ITMV=ITMV+I
                END IF
            ELSE
                IOUT(J,J,J)=ITMV
                ITMV=ITMV+I
            END IF
        ELSE
            IF (IOUTP(J,J,J).EQ.0) THEN
                ITMV=ITMV+J
                IF (ITMV.EQ.0) THEN
                    ITMV=0
                    ITMV=ITMV+J
                ELSE
                    ITMV=ITMV+J
                END IF
            ELSE
                IOUT(J,J,J)=ITMV
                ITMV=ITMV+J
            END IF
        END IF
    END IF
C COMPUTE CUSTOMER COSTS AROUND PRODUCT FOR CUSTOMER IN WAREHOUSE J
40 DO 50 LLL=1,NP
    IF (LPP(LLL,J,J).GE.0) THEN
        TEL=TEL+LPP(LLL,J,J)
        LLL=LLL+1
        IF (TEL.EQ.0) THEN
            TEL=TEL+LPP(LLL,J,J)
            LLL=LLL+1
        END IF
        IF (TEL.EQ.0) THEN
            TEL=TEL+LPP(LLL,J,J)
            LLL=LLL+1
        END IF
        IF (TEL.EQ.0) THEN
            TEL=TEL+LPP(LLL,J,J)
            LLL=LLL+1
        END IF
        IF (TEL.EQ.0) THEN
            TEL=TEL+LPP(LLL,J,J)
            LLL=LLL+1
        END IF
C CHECK WHETHER RATES FROM I TO LLL ARE IN FILE
    IF (LWXDI(I,J,J,J).GE.0) THEN
        IOUTP(J,J,J)=I
        GO TO 50
        IOUT(J,J,J)=J
        TEN=0
C IF (IOUTP(J,J,J).GE.0) THEN
        IOUT(J,J,J)=I
        GO TO 50
        IOUT(J,J,J)=J
        TEN=0
    END IF
45 UNITS=UNITS+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
    TELW=TELW+PRA(II,J,II,J,J,J)
9 WRITE(11,167)
C
WRITE(11,150)
WRITE(11,151)

150 FORMAT(25X,'NUMBER OF WAREHouses = ',110)
WRITE(11,152)

151 FORMAT(25X,'NUMBER OF CUSTOMERS = ',110)
WRITE(11,153)

152 FORMAT(25X,'EXACT OR HEURISTIC = ',110)
WRITE(11,154)

153 FORMAT(25X,'BRANCH & BOUND heuristic = ',110)
WRITE(11,155)

154 FORMAT(25X,'Node Selection RULE = ',110)
WRITE(11,156)

155 FORMAT(25X,'INITIAL UPPER BOUND = ',110)
WRITE(11,157)

156 FORMAT(30X,'USING OLD DATA')
WRITE(11,158)

GO TO 1 7863

7863 WRITE(11,159)
WRITE(11,160)

166 FORMAT(15X,'NEW PROBLEM')
READ(NF,51101/((IC(I),I=1,NW))
C
511 FORMAT(140)

512 FORMAT(140)
READ(NF,51201/((IC(I),J=1,NC))

513 FORMAT(25X,'VARIABLE COSTS ARE +/1')
READ(NF,51301/((IVG(I,J),J=1,NC))

7862 CONTINUE
C
7861 CONTINUE

C
C DEFINE ITC AND IVC DEPENDING ON JCDF VALUE
C
IF(JCDF=1.0) GO TO 7865
DO 10 J=1,NW
10 CONTINUE

C
IF(J=1) GO TO 7875
IC(J)=IC(J)+1
IF(J<NC) GO TO 7870
IF(J=NC) GO TO 7875

8 CONTINUE

10 CONTINUE
GO TO 7863

C
C 7861 IS THE BEGINNING OF KIMOWALA COMPUTATIONS
C
C
2350 IF(NODEI = 0) GO TO 2490
IF(MS.FQ, 45, NW.FQ, 65) GO TO 2470
IF(NODEF = T) GO TO 4450
2490 DO 2500 NW = 1, NW
IF(NODEI, NW) GO TO 2450
YINODE, NW = 0
GO TO 2500
2450 YINODE, NW = 1
2500 CONTINUE
GO TO 2500 IN = 1, NE
KWIN = KWIN(NODEI, IC)
IF (KWIN(NODEI, NW) GO TO 2450
IF(KWIN(NODEI, NW) = 2850
KWIN = KWIN(NODEI, IC)
KWIN(NODEI, IC) = 1
IF(KWIN = 2750
GO TO 2750
AA = IVCW(IN, IC)
XIN = X(NODEI, J)
IF(KWIN(NODEI, J, NW) = 02A411 IF(KWIN = XIN
KWIN = J = NW + 1
IF(KWIN = 2750
GO TO 2750
GO TO 2800
2650 CONTINUE
GO TO 2650
2700 IF(ILBS.L.T. AA = AA
IF(KWIN(NODEI, IC) = 02A411 IF(KWIN = 2700
GO TO 2750
2750 KWIN = NW
2800 CONTINUE
2850 XIN = X(NODEI, NW)
IF(KWIN(NODEI, NW) = 02A411 IF(KWIN = 2800
YINODE, NW) = XIN(NODE, NW)
2900 IF(NODEI = ZINODE) IVCW(IN, IC)
IF (NODER(W, FQ, 80) = 4450
KTR = 0
GO TO 3000 IN = 1, NW
IF(YINODE(IN, NW) FQ, 0) GO TO 2950
ZINODE = 2(NODEI = IF(NODEI = YINODE(IN)
GO TO 3000
KERR = KTR + 1
3000 CONTINUE
3001 FORMAT(1H3,300SP, 1110)
IF(KERR 3050, 3050, 4700
3050 IF(NODEI = FQ, 1) GO TO 3100
IF(NODEF = T) GO TO 3100
N FIRST = 41 GO TO 3100
NMOS = 4
IF(NODEI = 49) NMOS = 3
3100 IF(NODEF = 40) GO TO 3500
IF(NODEF, ZINODE) GO TO 3750
ZINODE = LIN
NAVL = NAVL + 1
KIN = MONI E = NODEI
GO TO 3200
3150 UBA = ZINODE
IF(UBAN = 40) GO TO 3200
IVC(1, J) + IVC(IST, J)
GO TO 6250
6230 DD 6240 K = 1, NPLANT
6240 LPPAR(1, K) = 1
6250 AINCR = AINCR + SORT (HMY(11) / 1001)
161 FORMAT ('4X, 15, E15.15')
7870 CONTINUE
IF (NV > 2, 1) AINLP = 1,
WRITE (11, 140) AINCR
198 FORMAT ('4X, 15, E15.6')
7864 FORMAT ('4X, 4A4, I4, 4X, 4A4, 2117')
WRITE (11, 162)
WRITE (11, 164)
164 FORMAT ('2X, 9X, CUSTOMER NAME: ', V CUST FOR , 15, ' WHCST ')
0500 J = J + 1, NC
ISTAR = INFORTNUM(J)
IST = INFORT(J)
WRITE (11, 7864) (J, I = 1, 4), J, (INAME(J, K), K = 1, 41),
*ISTAR, IVCC(ISTAR, J)
C
WRITE (11, 7864) (J, I = 1, 4), J, (INAME(J, K), K = 1, 41),
*ISTAR, IVCC(ISTAR, J)
C
WRITE (11, 7864) (J, I = 1, 4), J, (INAME(J, K), K = 1, 41),
*ISTAR, IVCC(ISTAR, J)
C
GO TO 7000
6290 IZAR(J, K) = ISTAR
5700 CONTINUE
INIT = 0
C
GO TO 200
5805 IF (J = OF, OF, 21) GO TO 5810
ELL = LLL(Y)
IF (J = OF, NPLANT) GO TO 200
5800 CONTINUE
5810 RETURN
END
APPENDIX H
MANOVA's and Duncan's Tests

The multivariate analyses of variance and the Duncan's Multiple Range Tests are contained in this Appendix. The results of the entire data set appear first, followed by each combination of the demand product characteristics investigated. The abbreviations of the variables are:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Abbreviation</th>
<th>Possible Values</th>
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<tbody>
<tr>
<td>Mean Order Weight</td>
<td>MOW</td>
<td>500,1500 pounds</td>
</tr>
<tr>
<td>Total Annual Orders</td>
<td>TAO</td>
<td>50,000; 250,000</td>
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<tr>
<td>Plant Location</td>
<td>PLANT</td>
<td>71 = Newark, N.J.</td>
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<tr>
<td></td>
<td></td>
<td>432 = Columbus, Ohio</td>
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<tr>
<td></td>
<td></td>
<td>752 = Dallas, Texas</td>
</tr>
<tr>
<td>Geographic Distribution of Demand</td>
<td>GEOG</td>
<td>1 = by population</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 = by manufacturer's value added</td>
</tr>
<tr>
<td>Product Class</td>
<td>PRODS</td>
<td>0 = all three classes</td>
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<tr>
<td></td>
<td></td>
<td>1 = class 60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 = class 77.5</td>
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<tr>
<td></td>
<td></td>
<td>3 = class 100</td>
</tr>
<tr>
<td>System Structure</td>
<td>STRUC</td>
<td>0 = plant - 0 days holding time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = plant - 1 day holding time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 = plant - 4 days holding time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 = warehouse - 0 days holding time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 = warehouse - 1 day holding time</td>
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<td></td>
<td></td>
<td>5 = warehouse - 4 days holding time</td>
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<td>Cost per hundred weight</td>
<td>COST</td>
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<tr>
<td>Mean Delivery Time</td>
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<td>Delivery Time Variance</td>
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### General Linear Models Procedure

#### Number of Observations in Data Set = 2060

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<th>C.V.</th>
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#### Contrasts

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<td>1</td>
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#### General Linear Models Procedure

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<th>Mean Square</th>
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<th>C.V.</th>
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<td>647.59194737</td>
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<td>0.0001</td>
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<td><strong>Error</strong></td>
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<td>2414.97529867</td>
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#### Contrasts

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#### General Linear Models Procedure

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<th>C.V.</th>
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<td>0.92375364</td>
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#### Contrasts

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### GENERAL LINEAR MODELS PROCEDURE

**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

Means with the same letter are not significantly different.

**Alpha Level**: .01  \( df = 2874 \)  \( M_S = 7.7352 \)

<table>
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<tr>
<td>A</td>
<td>81.450265</td>
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<tr>
<td>B</td>
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</tr>
<tr>
<td>B</td>
<td>50.437137</td>
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<td>C</td>
<td>29.574877</td>
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### GENERAL LINEAR MODELS PROCEDURE

**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

Means with the same letter are not significantly different.

**Alpha Level**: .01  \( df = 2874 \)  \( M_S = 0.84618 \)

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<th>STRC</th>
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<tbody>
<tr>
<td>A</td>
<td>6.794786</td>
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<td>2</td>
</tr>
<tr>
<td>B</td>
<td>6.344629</td>
<td>400</td>
<td>1</td>
</tr>
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<td>C</td>
<td>6.016948</td>
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</tr>
<tr>
<td>D</td>
<td>5.208304</td>
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</tr>
<tr>
<td>E</td>
<td>4.862171</td>
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<tr>
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### GENERAL LINEAR MODELS PROCEDURE

**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV**

Means with the same letter are not significantly different.

**Alpha Level**: .01  \( df = 2874 \)  \( M_S = 0.84623 \)

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<td>C</td>
<td>10.276494</td>
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<td>D</td>
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### General Linear Models Procedure

**Dependent Variable: COST**

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<th>R-Square</th>
<th>C.V.</th>
</tr>
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<tbody>
<tr>
<td>Model</td>
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<td>8.839632789</td>
<td>829.56</td>
<td>0.0001</td>
<td>0.994152</td>
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**Dependent Variable: T**

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<th>C.V.</th>
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<th>C.V.</th>
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<th>Pr &gt; F</th>
<th>R-Square</th>
<th>C.V.</th>
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<td>1499.95</td>
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### Duncan's Multiple Range Test for Variable COST

Means with the same letter are not significantly different.

**Alpha Level: .01**

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<td>B</td>
<td>16.066600</td>
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### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

**Alpha Level: .01**

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</tr>
<tr>
<td>B</td>
<td>5.991680</td>
<td>5</td>
</tr>
<tr>
<td>C</td>
<td>4.612490</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>3.595869</td>
<td>5</td>
</tr>
<tr>
<td>E</td>
<td>2.979160</td>
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</tr>
<tr>
<td>F</td>
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**Grand Mean**: 4.2441228

**Grand Standard Deviation**: 3.6345327
### General Linear Model Procedure

**Dependent Variable: COST**

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<th>F Value</th>
<th>Pr &gt; F</th>
<th>R-Square</th>
<th>C.V.</th>
<th>Cost Mean</th>
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### General Linear Models Procedure

**Dependent Variable: T**

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### General Linear Models Procedure

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### Duncan's Multiple Range Test for Variable COST

**Means with the Same Letter Are Not Significantly Different.**

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### Duncan's Multiple Range Test for Variable T

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<td>D</td>
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### Duncan's Multiple Range Test for Variable TV

**Means with the Same Letter Are Not Significantly Different.**

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### General Linear Models Procedure

**Dependent Variable: COST**

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### General Linear Models Procedure

**Dependent Variable: Y**

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### General Linear Models Procedure

**Dependent Variable: TV**

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### Duncan's Multiple Range Test for Variable COST

Means with the same letter are not significantly different.

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### Duncan's Multiple Range Test for Variable Y

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### General Linear Models Procedure

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**Dependent Variable: TV**

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### Duncan's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

### Duncan's Multiple Range Test for Variable TV

Means with the same letter are not significantly different.
### DEPENDENT VARIABLE: COST

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DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

Means with the same letter are not significantly different.

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DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

Means with the same letter are not significantly different.

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

Means with the same letter are not significantly different.

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV

Means with the same letter are not significantly different.
### General Linear Models Procedure

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### Duncan's Multiple Range Test for Variable COST

Means with the same letter are not significantly different.

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### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

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### Duncan's Multiple Range Test for Variable TV

Means with the same letter are not significantly different.
### General Linear Models Procedure

**Dependent Variable: COST**

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<tbody>
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### General Linear Models Procedure

**Dependent Variable: T**

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### General Linear Models Procedure

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**Duncan's Multiple Range Test for Variable COST**

Means with the same letter are not significantly different.

**Alpha Level: .01**

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**Duncan's Multiple Range Test for Variable TV**

Means with the same letter are not significantly different.

**Alpha Level: .01**

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### General Linear Models Procedure

**Dependent Variable: COST**

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**Dependent Variable: T**

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**Dependent Variable: TV**

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**Duncan's Multiple Range Test for Variable COST**

Means with the same letter are not significantly different.

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**Duncan's Multiple Range Test for Variable T**

Means with the same letter are not significantly different.

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### General Linear Models Procedure

#### Dependent Variable: COST

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#### Duncan's Multiple Range Test for Variable COST

Means with the same letter are not significantly different.

Alpha Level: 0.01

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#### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

Alpha Level: 0.01

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### General Linear Models Procedure

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### Duncan's Multiple Range Test for Variable COST

Means with the same letter are not significantly different.

**Alpha Level = .01**

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### Duncan's Multiple Range Test for Variable TV

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### GENERAL LINEAR MODELS PROCEDURE

**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

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### GENERAL LINEAR MODELS PROCEDURE

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL: .01**

**DF=24**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL: .01**

**DF=24**
### Dependent Variable: COST

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### Dependent Variable: TV

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### Duncan's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.
### General Linear Models Procedure

#### Dependent Variable: COST

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#### Dependent Variable: T

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### General Linear Models Procedure

#### Means with the Same Letter are Not Significantly Different

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### Duncan's Multiple Range Test for Dependent Variable COST

#### Duncan's Multiple Range Test for Variable T

#### Duncan's Multiple Range Test for Variable TV

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### General Linear Models Procedure

#### Dependent Variable: COST

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#### General Linear Models Procedure

**Duncan's Multiple Range Test for Variable COST**

Means with the same letter are not significantly different.

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**Duncan's Multiple Range Test for Variable T**

Means with the same letter are not significantly different.

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### General Linear Models Procedure

#### Dependent Variable: Cost

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#### Dependent Variable: T

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**Duncan’s Multiple Range Test for Variable Cost**

Means with the same letter are not significantly different.

**Alpha Levels: .01 DF=24 MS=0.066246**

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**Duncan’s Multiple Range Test for Variable T**

Means with the same letter are not significantly different.

**Alpha Levels: .01 DF=24 MS=0.066246**

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## General Linear Models Procedure

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### Duncan's Multiple Range Test for Variable COST

Means with the same letter are not significantly different.

#### Groups

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### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

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### General Linear Models Procedure

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### General Linear Models Procedure

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### General Linear Models Procedure

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### Duncan's Multiple Range Test for Variable Cost

#### Means with the Same Letter are Not Significantly Different.

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### Duncan's Multiple Range Test for Variable T

#### Means with the Same Letter are Not Significantly Different.

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### General Linear Models Procedure

**Dependent Variable: COST**

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**Dependent Variable: T**

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**Dependent Variable: TV**

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### Duncan's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

**Alpha Level: .01**

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### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

**Alpha Level: .01**

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### Duncan's Multiple Range Test for Variable TV

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**Alpha Level: .01**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL: .01**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

Means with the same letter are not significantly different.

**Alphabetical Level : .01**

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**Alphabetical Level : .01**

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#### GENERAL LINEAR MODEL PROCEDURE

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#### GENERAL LINEAR MODEL PROCEDURE

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

Means with the same letter are not significantly different.

**ALPHA LEVEL: .01**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

Means with the same letter are not significantly different.

**ALPHA LEVEL: .01**

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### General Linear Models Procedure

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### General Linear Models Procedure

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### General Linear Models Procedure

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### Duncan's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

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### Duncan's Multiple Range Test for Variable TV

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### General Linear Models Procedure

**Dependent Variable: COST**

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- **Source**: Type I SS
- **F Value**: 1926.86
- **Pr > F**: 0.0001
- **R-Square**: 0.995347
- **C.V.**: 0.2264

### General Linear Models Procedure

**Dependent Variable: T**

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<th>R-Square</th>
<th>C.V.</th>
<th>TV Mean</th>
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<tbody>
<tr>
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- **Source**: Type I SS
- **F Value**: 12283.30
- **Pr > F**: 0.0001
- **R-Square**: 0.999669
- **C.V.**: 0.5165

### General Linear Models Procedure

**Dependent Variable: TV**

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<th>C.V.</th>
<th>TV Mean</th>
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<tr>
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- **Source**: Type I SS
- **F Value**: 512.66
- **Pr > F**: 0.0001
- **R-Square**: 0.999726
- **C.V.**: 1.477

**Duncan's Multiple Range Test for Variable COST**

Means with the same letter are not significantly different.

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<thead>
<tr>
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<th>STRUC</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>7.618000</td>
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<td>B</td>
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</tr>
<tr>
<td>C</td>
<td>6.557000</td>
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<td>D</td>
<td>5.165000</td>
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<td>5</td>
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<td>E</td>
<td>4.250000</td>
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**Duncan's Multiple Range Test for Variable T**

Means with the same letter are not significantly different.

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<th>STRUC</th>
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**Duncan's Multiple Range Test for Variable TV**

Means with the same letter are not significantly different.
### General Linear Models Procedure

**Dependent Variable: COST**

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<th>C.V.</th>
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<tbody>
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**Contrast**

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<th>Pr &gt; F</th>
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<tbody>
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<td>PLY-ROC VS PLY-1DAY</td>
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<tr>
<td>PLY-ROC VS PLY-4DAY</td>
<td>1</td>
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<tr>
<td>WISE-Roc VS WISE-1DA</td>
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<tr>
<td>WISE-Roc VS WISE-4DA</td>
<td>1</td>
<td>0.52548546</td>
<td>0.0001</td>
</tr>
<tr>
<td>PLY-Roc VS ALL OTHER</td>
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<td>0.94259425</td>
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<td>PLY-CON Vs ALL OTHER</td>
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**Dependent Variable: TV**

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<th>Mean Square</th>
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<th>R-Square</th>
<th>C.V.</th>
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**Contrast**

<table>
<thead>
<tr>
<th>Source</th>
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<tbody>
<tr>
<td>PLY-Roc VS PLY-1DAY</td>
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<td>WISE-Roc VS WISE-1DA</td>
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<td>PLY-CON Vs ALL OTHER</td>
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### Duncan's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

**Alpha Level**: 0.01

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<th>Struc</th>
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### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

**Alpha Level**: 0.01

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<th>Struc</th>
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<td>C</td>
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<td>D</td>
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### DEPENDENT VARIABLE: COST

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<th>F VALUE</th>
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<th>R-SQUARE</th>
<th>C.V.</th>
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### Independent Variables: T

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<th>R-SQUARE</th>
<th>C.V.</th>
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<tr>
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### Independent Variables: TV

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<th>R-SQUARE</th>
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### Duncan's Multiple Range Test for Significant Differences

#### Means with the Same Letter are Not Significantly Different.

**Alpha Level: .01**

<table>
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<tr>
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<th>MEAN</th>
<th>N</th>
<th>STRUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>7.618296</td>
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<td>B</td>
<td>6.354400</td>
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<td>C</td>
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<td>4.259889</td>
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<td>3.792000</td>
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**Alpha Level: .05**

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<th>STRUC</th>
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### Source

**Model**: Engineering, Economics, Sociology

**Error**: Random

**Corrected Total**: Engineering, Economics, Sociology
### General Linear Models Procedure

**Dependent Variable:** COST

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
<th>R-Square</th>
<th>C.V.</th>
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<tbody>
<tr>
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**Contrast**

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<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
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<tbody>
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<td>Source 1 vs Source 2</td>
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### General Linear Models Procedure

**Dependent Variable:** T

<table>
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<th>Mean Square</th>
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<th>Pr &gt; F</th>
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**Contrast**

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### General Linear Models Procedure

**Dependent Variable:** TV

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### Duncan's Multiple Range Test for Variable COST

Means with the same letter are not significantly different.

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<td>B</td>
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<td>D</td>
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### Duncan's Multiple Range Test for Variable T

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### Duncan's Multiple Range Test for Variable TV

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### DEPENDENT VARIABLE: COST

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**Nov-580**  **Tao=200000**  **Platt=71**  **Gedoc=2**  **Froeb=0**

### GENERAL LINEAR MODELS PROCEDURE

### DEPENDENT VARIABLE: T

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**Nov-580**  **Tao=200000**  **Platt=71**  **Gedoc=2**  **Froeb=0**

### GENERAL LINEAR MODELS PROCEDURE

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**Duncan’s Multiple Range Test for Variable Cost**

Means with the same letter are not significantly different.

**Alpha Level = .01**  **DF = 24**  **N = 99447850**

**GROUPING**  **MEAN**  **N**  **STDC**

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**Duncan’s Multiple Range Test for Variable T**

Means with the same letter are not significantly different.

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**GROUPING**  **MEAN**  **N**  **STDC**

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### DEPENDENT VARIABLE: T

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

**Means with the same letter are not significantly different.**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

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**Means with the same letter are not significantly different.**

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### General Linear Models Procedure

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**Bartlett's Multiple Range Test for Variable Cost**

Means with the same letter are not significantly different.

**Alpha Level = 0.01**

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**Bartlett's Multiple Range Test for Variable T**

Means with the same letter are not significantly different.

**Alpha Level = 0.01**

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### General Linear Models Procedure

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### General Linear Models Procedure

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### General Linear Models Procedure

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### Duncan’s Multiple Range Test for Variable COST

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### Duncan’s Multiple Range Test for Variable TV

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***Means with the same letter are not significantly different.***
### DEPENDENT VARIABLE: COST

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### DEPENDENT VARIABLE: TV

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL=.01**  **DF=24**  **MS=6.0292975**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL=.01**  **DF=24**  **MS=7.7968-04**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL=.01**  **DF=24**  **MS=6.335514**

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### DEPENDENT VARIABLE: COST

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL = .01**

**GROUPING**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL = .01**

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### General Linear Models Procedure

#### Dependent Variable: Cost

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#### General Linear Models Procedure

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#### General Linear Models Procedure

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### Duncan's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

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### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

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### DEPENDENT VARIABLE: COST

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT:**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT:**

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## General Linear Models Procedure

**Dependent Variable: COST**

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**Contrast**

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**Dependent Variable: T**

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**Contrast**

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**Dependent Variable: TV**

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**Contrast**

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**Duncan's Multiple Range Test for Variable COST**

Means with the same letter are not significantly different.

**Alpha Level: .01**

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**Duncan's Multiple Range Test for Variable T**

Means with the same letter are not significantly different.

**Alpha Level: .01**

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**DEPENDENT VARIABLE: T**

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**DEPENDENT VARIABLE: TV**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV**

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DEPENDENT VARIABLE: COST

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SUMMARY OF MODEL

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CONTRAST DF

| PLT-NOC VS PLT-1DAY       | 1  | 18.09280448 | 1.18    | 0.281 |          |         |       |
| PLT-NOC VS PLT-4DAY       | 1  | 19.80533229 | 1.18    | 0.281 |          |         |       |
| WISE-NOC VS WISE-1DA      | 1  | 0.35070817  | 4.69    | 0.035 |          |         |       |
| WISE-NOC VS WISE-4DA      | 1  | 0.31895361  | 4.69    | 0.035 |          |         |       |
| PLT-NOC VS ALL OTHER      | 1  | 0.04923236  | 0.004   | 0.956 |          |         |       |
| PLA-COR VS ALL OTHER      | 1  | 27.46812377 | 228.26  | 0.0001|          |         |       |

DEPENDENT VARIABLE: T

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SUMMARY OF MODEL

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CONTRAST DF

| PLT-NOC VS PLT-1DAY       | 1  | 3.70552550  | 39.71   | 0.0001 |          |         |       |
| PLT-NOC VS PLT-4DAY       | 1  | 1.85529219  | 450.75  | 0.0001 |          |         |       |
| WISE-NOC VS WISE-1DA      | 1  | 1.42161520  | 547.82  | 0.0001 |          |         |       |
| WISE-NOC VS WISE-4DA      | 1  | 0.72443580  | 1370.46 | 0.0001 |          |         |       |
| PLT-NOC VS ALL OTHER      | 1  | 0.46923760  | 111.41  | 0.0001 |          |         |       |
| PLA-COR VS ALL OTHER      | 1  | 12.28326045 | 2940.53 | 0.0001 |          |         |       |

DEPENDENT VARIABLE: TV

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<th>R-SQUARE</th>
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SUMMARY OF MODEL

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CONTRAST DF

| PLT-NOC VS PLT-1DAY       | 1  | 29.52211240 | 227.34  | 0.0001 |          |         |       |
| PLT-NOC VS PLT-4DAY       | 1  | 10.97772220 | 123.53  | 0.0001 |          |         |       |
| WISE-NOC VS WISE-1DA      | 1  | 8.78864800  | 20.37   | 0.0001 |          |         |       |
| WISE-NOC VS WISE-4DA      | 1  | 15.89949948 | 172.68  | 0.0001 |          |         |       |
| PLT-NOC VS ALL OTHER      | 1  | 13.29404400 | 151.92  | 0.0001 |          |         |       |
| PLA-COR VS ALL OTHER      | 1  | 24.49524125 | 250.13  | 0.0001 |          |         |       |

DUNCAN' S MULTIPLE RANGE TEST FOR VARIABLE COST

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.01 DF=24 MEAN=.0064177

GROUPING | MEAN | N | STRUC
---------|------|---|---------
A         | 8.063000 | 5 | 2
B         | 5.453200 | 5 | 1
C         | 5.062200 | 5 | 0
D         | 4.643400 | 5 | 3
E         | 4.072200 | 5 | 4
F         | 3.303200 | 5 | 5

DUNCAN' S MULTIPLE RANGE TEST FOR VARIABLE T

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.01 DF=24 MEAN=.0064177

GROUPING | MEAN | N | STRUC
---------|------|---|---------
A         | 11.565000 | 5 | 5
B         | 11.361200 | 5 | 6
C         | 9.972600  | 5 | 4
D         | 9.265300  | 5 | 2
E         | 9.126000  | 5 | 3
F         | 7.924000  | 5 | 1
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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

Means with the same letter are not significantly different.

**Alpha level**: .01

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

Means with the same letter are not significantly different.

**Alpha level**: .01

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

*Means with the same letter are not significantly different.*

**Alpha Level: .01**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

*Means with the same letter are not significantly different.*

**Alpha Level: .01**

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### GENERAL LINEAR MODELS PROCEDURE

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

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### General Linear Models Procedure

**Dependent Variable: COST**

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### General Linear Models Procedure

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### General Linear Models Procedure

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**Duncan's Multiple Range Test for Variable COST**

<table>
<thead>
<tr>
<th>Duncan's Multiple Range Test for Variable COST</th>
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</thead>
<tbody>
<tr>
<td>Means with the same letter are not significantly different.</td>
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</table>

**Alpha level = .01**

<table>
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<th>DF=24</th>
<th>MS=0.00261</th>
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**Duncan's Multiple Range Test for Variable T**

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**Alpha level = .01**

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**Means with the same letter are not significantly different.**

**Alpha Level = .01**

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<th>MS=0.00261</th>
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</thead>
<tbody>
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**Means with the same letter are not significantly different.**
### General Linear Models Procedure

**Dependent Variable: Cost**

<table>
<thead>
<tr>
<th>Source</th>
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<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
<th>R-Square</th>
<th>C.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>29.06542225</td>
<td>5.83886425</td>
<td>1120.68</td>
<td>0.0001</td>
<td>0.995744</td>
<td>0.2246</td>
</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>0.12579161</td>
<td>0.052116</td>
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<tr>
<td>Corrected Total</td>
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<td>29.96121411</td>
<td>0.9721163</td>
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<table>
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<th>Type I SS</th>
<th>F Value</th>
<th>Pr &gt; F</th>
<th>Type IV SS</th>
<th>F Value</th>
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### General Linear Models Procedure

**Dependent Variable: T**

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<th>C.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>69.0657977</td>
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<tr>
<td>Error</td>
<td>24</td>
<td>0.01454329</td>
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<th>Type IV SS</th>
<th>F Value</th>
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<tr>
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### General Linear Models Procedure

**Dependent Variable: TV**

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<tr>
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<th>F Value</th>
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<th>R-Square</th>
<th>C.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>64.18352257</td>
<td>12.62976451</td>
<td>513.88</td>
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<td>Error</td>
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<td>0.5977060</td>
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<td></td>
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<table>
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<th>Source</th>
<th>DF</th>
<th>Type I SS</th>
<th>F Value</th>
<th>Pr &gt; F</th>
<th>Type IV SS</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>64.18352257</td>
<td>513.88</td>
<td>0.0001</td>
<td>64.18352257</td>
<td>513.88</td>
<td>0.0001</td>
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**Duncan's Multiple Range Test for Variable Cost**

Means with the same letter are not significantly different.

**Alpha Level = .01**

<table>
<thead>
<tr>
<th>Grouping</th>
<th>DF = 24</th>
<th>NS = 60032116</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>33.564973</td>
<td>5  4</td>
</tr>
<tr>
<td>B</td>
<td>53.122306</td>
<td>5  5</td>
</tr>
<tr>
<td>C</td>
<td>62.454629</td>
<td>6  6</td>
</tr>
<tr>
<td>D</td>
<td>31.650177</td>
<td>5  3</td>
</tr>
<tr>
<td>E</td>
<td>30.660086</td>
<td>5  2</td>
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**Duncan's Multiple Range Test for Variable T**

Means with the same letter are not significantly different.

**Alpha Level = .01**

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<tr>
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<tr>
<td>A</td>
<td>12.590440</td>
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</tr>
<tr>
<td>B</td>
<td>11.890900</td>
<td>5  5</td>
</tr>
<tr>
<td>C</td>
<td>11.660600</td>
<td>5  5</td>
</tr>
<tr>
<td>D</td>
<td>10.547200</td>
<td>4  4</td>
</tr>
<tr>
<td>E</td>
<td>8.219220</td>
<td>4  4</td>
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**Duncan's Multiple Range Test for Variable TV**

Means with the same letter are not significantly different.
### GENERAL LINEAR MODELS PROCEDURE

**DEPENDENT VARIABLE: COST**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SUM OF SQUARES</th>
<th>MEAN SQUARE</th>
<th>F VALUE</th>
<th>PR &gt; F</th>
<th>R-SQUARE</th>
<th>C.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL</td>
<td>5</td>
<td>28.67179126</td>
<td>1.734352725</td>
<td>2354.75</td>
<td>0.0001</td>
<td>0.979665</td>
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<td>0.05244457</td>
<td>0.00244523</td>
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</tr>
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<table>
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<tr>
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<th>DF</th>
<th>TYPE IV SS</th>
<th>F VALUE</th>
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</tr>
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<tbody>
<tr>
<td>STRUC</td>
<td>5</td>
<td>28.67179126</td>
<td>2354.75</td>
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<td>5</td>
<td>28.67179126</td>
<td>2354.75</td>
<td>0.0001</td>
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</table>

<table>
<thead>
<tr>
<th>CONTRAST</th>
<th>DF</th>
<th>SS</th>
<th>F VALUE</th>
<th>PR &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLT-MOC VS PLT-1DAY</td>
<td>1</td>
<td>5.74642567</td>
<td>2354.75</td>
<td>0.0001</td>
</tr>
<tr>
<td>PLT-MOC VS PLT-4DAY</td>
<td>1</td>
<td>9.38164258</td>
<td>3394.76</td>
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<tr>
<td>WISE-MOC VS WISE-1DA</td>
<td>1</td>
<td>1.61614774</td>
<td>664.27</td>
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<tr>
<td>WISE-MOC VS WISE-4DA</td>
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<td>0.0001</td>
</tr>
<tr>
<td>PLT-MOC VS ALL OTHER</td>
<td>1</td>
<td>1.85962487</td>
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</tr>
<tr>
<td>PLA-CON VS ALL OTHER</td>
<td>1</td>
<td>26.16242959</td>
<td>10745.32</td>
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**DEPENDENT VARIABLE: T**

<table>
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<th>PR &gt; F</th>
<th>R-SQUARE</th>
<th>C.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL</td>
<td>5</td>
<td>31.36491397</td>
<td>6.27292777</td>
<td>2629.41</td>
<td>0.0001</td>
<td>0.968176</td>
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<td>2629.41</td>
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<td>5</td>
<td>31.36491397</td>
<td>2629.41</td>
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<th>F VALUE</th>
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<tbody>
<tr>
<td>PLT-MOC VS PLT-1DAY</td>
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<td>PLT-MOC VS PLT-4DAY</td>
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<td>WISE-MOC VS WISE-1DA</td>
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<td>WISE-MOC VS WISE-4DA</td>
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</tr>
<tr>
<td>PLA-CON VS ALL OTHER</td>
<td>1</td>
<td>17.19709427</td>
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**DEPENDENT VARIABLE: TV**

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<th>R-SQUARE</th>
<th>C.V.</th>
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<tr>
<td>MODEL</td>
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<td>ERROR</td>
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<th>DF</th>
<th>TYPE IV SS</th>
<th>F VALUE</th>
<th>PR &gt; F</th>
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<tbody>
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<td>14.36943727</td>
<td>69.72</td>
<td>0.0001</td>
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<tr>
<th>CONTRAST</th>
<th>DF</th>
<th>SS</th>
<th>F VALUE</th>
<th>PR &gt; F</th>
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</thead>
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<tr>
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</tr>
<tr>
<td>PLT-MOC VS ALL OTHER</td>
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<td>0.0001</td>
</tr>
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<td>PLA-CON VS ALL OTHER</td>
<td>1</td>
<td>2.54532677</td>
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</table>

**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL: .01**

**GROUPING**

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<tr>
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<th>N</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>7.295400</td>
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<tr>
<td>B</td>
<td>6.801000</td>
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<tr>
<td>C</td>
<td>6.729600</td>
</tr>
<tr>
<td>D</td>
<td>5.319600</td>
</tr>
<tr>
<td>E</td>
<td>5.280000</td>
</tr>
<tr>
<td>F</td>
<td>4.561400</td>
</tr>
</tbody>
</table>

**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL: .01**

**GROUPING**

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<thead>
<tr>
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<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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</tr>
<tr>
<td>B</td>
<td>7.907200</td>
</tr>
<tr>
<td>C</td>
<td>7.152400</td>
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<td>D</td>
<td>6.009200</td>
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<td>E</td>
<td>5.777400</td>
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<tr>
<td>F</td>
<td>3.931800</td>
</tr>
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</table>

**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV**

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

**ALPHA LEVEL: .01**

**GROUPING**

<table>
<thead>
<tr>
<th>MEAN</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>7.295400</td>
</tr>
<tr>
<td>B</td>
<td>6.801000</td>
</tr>
<tr>
<td>C</td>
<td>6.729600</td>
</tr>
<tr>
<td>D</td>
<td>5.319600</td>
</tr>
<tr>
<td>E</td>
<td>5.280000</td>
</tr>
<tr>
<td>F</td>
<td>4.561400</td>
</tr>
</tbody>
</table>
### GENERAL LINEAR MODELS PROCEDURE

**DEPENDENT VARIABLE: COST**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SUM OF SQUARES</th>
<th>MEAN SQUARE</th>
<th>F VALUE</th>
<th>PR &gt; F</th>
<th>R-SQUARE</th>
<th>C.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL</td>
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<td>32.66205858</td>
<td>10.52261812</td>
<td>3672.14</td>
<td>0.0001</td>
<td>0.4926955</td>
<td>0.1475</td>
</tr>
<tr>
<td>ERROR</td>
<td>24</td>
<td>0.36063599</td>
<td>0.0008019</td>
<td>STD DEV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CORRECTED TOTAL</td>
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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

**MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV

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### General Linear Models Procedure

**Dependent Variable: COST**

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**Contrast**

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**Dependent Variable: T**

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**Contrast**

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**Dependent Variable: TV**

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**Contrast**

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**Duncan's Multiple Range Test for Variable COST**

Means with the same letter are not significantly different.

### Alpha Level: .01

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**Duncan's Multiple Range Test for Variable T**

Means with the same letter are not significantly different.

### Alpha Level: .01

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### General Linear Models Procedure

**Dependent Variable: COST**

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<th>C.V.</th>
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### General Linear Models Procedure

**Dependent Variable: T**

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### General Linear Models Procedure

**Dependent Variable: TV**

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### Duncan's Multiple Range Test for Variable COST

**Means with the same letter are not significantly different.**

**Alpha Level=.01**

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### Duncan's Multiple Range Test for Variable T

**Means with the same letter are not significantly different.**

**Alpha Level=.01**

**Alpha Level=.05**

### Duncan's Multiple Range Test for Variable TV

**Means with the same letter are not significantly different.**

**Alpha Level=.01**

**Alpha Level=.05**
### General Linear Models Procedure

**Dependent Variable: Cost**

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### General Linear Models Procedure

**Dependent Variable: T**

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### General Linear Models Procedure

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### Duncan's Multiple Range Test for Variable Cost

**Means with the Same Letter are Not Significantly Different**

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<tr>
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### Duncan's Multiple Range Test for Variable T

**Means with the Same Letter are Not Significantly Different**

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### General Linear Models Procedure

#### Dependent Variable: COST

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#### Dependent Variable: T

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#### Dependent Variable: TV

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### Duncan's Multiple Range Test for Variable COST

Means with the same letter are not significantly different.

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<tr>
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<td>B</td>
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### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

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### Duncan's Multiple Range Test for Variable TV

Means with the same letter are not significantly different.
### General Linear Models Procedure

**Dependent Variable: Cost**

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<th>C.V.</th>
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**Dependent Variable: T**

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**Dependent Variable: TV**

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**Duncan's Multiple Range Test for Variable Cost**

<p>| Means with the Same Letter Are Not Significantly Different. |
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**Duncan's Multiple Range Test for Variable T**

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|---|---|---|---|---|
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### GENERAL LINEAR MODELS PROCEDURE

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

**Means with the same letter are not significantly different.**

**Alpha Level: .01**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

**Means with the same letter are not significantly different.**

**Alpha Level: .01**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV

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**Alpha Level: .01**

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### General Linear Models Procedure

#### Dependent Variable: Cost

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#### Duncan's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

**Duncan's Multiple Range Test for Variable Cost**

**Alpha Level = 0.05**

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#### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

**Duncan's Multiple Range Test for Variable T**

**Alpha Level = 0.05**

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**Means with the Same Letter are Not Significantly Different.**

**Alpha Level = 0.05**

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### General Linear Models Procedure

**Dependent Variable: COST**

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**Dependent Variable: T**

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**Dependent Variable: TV**

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**Duncan's Multiple Range Test for Variable Cost**

Means with the same letter are not significantly different.

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**Duncan's Multiple Range Test for Variable T**

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### GENERAL LINEAR MODELS PROCEDURE

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**DEPENDENT VARIABLE: T**

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**DURCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

Means with the same letter are not significantly different.

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<td>D</td>
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**DURCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

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**DURCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV**

Means with the same letter are not significantly different.

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DETERMINANT VARIABLE: COST

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DETERMINANT VARIABLE: T

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DETERMINANT VARIABLE: TV

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DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL*: .01

GROUPING | MEAN | N | STRUC
---------|------|---|-------
A         | 7.472208 | 5 | 2
B         | 6.765603 | 5 | 1
C         | 6.513800 | 5 | 0
D         | 5.797200 | 5 | 5
E         | 4.566900 | 5 | 4
F         | 3.967400 | 5 | 3

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL*: .01

GROUPING | MEAN | N | STRUC
---------|------|---|-------
A         | 16.366400 | 5 | 2
B         | 15.966400 | 5 | 1
C         | 12.976400 | 5 | 9
D         | 12.126500 | 5 | 5
E         | 8.126000  | 5 | 4
F         | 8.566200  | 5 | 3
## General Linear Models Procedure

### Dependent Variable: Cost

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### Contrast

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### Duncan's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

**Alpha Level:** .01  **DF=24**  **MS=0.005865**

**Grouping**

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### Duncan's Multiple Range Test for Variable TV

Means with the same letter are not significantly different.

**Alpha Level:** .01  **DF=24**  **MS=0.004492**

**Grouping**

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Means with the same letter are not significantly different.
**DEPENDENT VARIABLE: COST**

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**DEPENDENT VARIABLE: T**

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**DEPENDENT VARIABLE: TV**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

Means with the same letter are not significantly different.

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

Means with the same letter are not significantly different.

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### DEPENDENT VARIABLE: COST

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**NEW=1806** **TWO=50800** **PLANT=422** **CEDO=1** **PRODS=3**

### DEPENDENT VARIABLE: T

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### SOURCE

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**NEW=1806** **TWO=50800** **PLANT=422** **CEDO=1** **PRODS=3**

### DEPENDENT VARIABLE: TV

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### SOURCE

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**DUNCAN’S MULTIPLE RANGE TEST FOR VARIABLE COST**

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

**ALPHA LEVEL=.01** **DF=24** **MS=1.408771**

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**DUNCAN’S MULTIPLE RANGE TEST FOR VARIABLE T**

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

**ALPHA LEVEL=.01** **DF=24** **MS=0.674624**

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### General Linear Models Procedure

#### Dependent Variable: Cost

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<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
<th>R-Square</th>
<th>C.V.</th>
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<tbody>
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#### Dependent Variable: T

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<th>C.V.</th>
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#### Dependent Variable: TV

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### Duncan's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

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### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

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### Duncan's Multiple Range Test for Variable TV

Means with the same letter are not significantly different.

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### DEPENDENT VARIABLE: COST

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<th>R-Square</th>
<th>C.V.</th>
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<td>1.98644362</td>
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<td>0.0001</td>
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<td>0.04337724</td>
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### DEPENDENT VARIABLE: TV

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

**Means with the same letter are not significantly different.**

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<th>NE</th>
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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

**Means with the same letter are not significantly different.**

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### General Linear Models Procedure

**Dependent Variable: Cost**

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**Source**

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**Dependent Variable: T**

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<th>R-Square</th>
<th>C.V.</th>
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**Source**

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<th>F Value</th>
<th>Pr &gt; F</th>
<th>Type IV SS</th>
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<th>Pr &gt; F</th>
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**Dependent Variable: TV**

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**Duncan's Multiple Range Test for Variable Cost**

**Means with the Same Letter Are Not Significantly Different.**

**Alpha Level: 0.01**

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**Duncan's Multiple Range Test for Variable T**

**Means with the Same Letter Are Not Significantly Different.**

**Alpha Level: 0.01**

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### DEPENDENT VARIABLE: COST

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

**Means with the same letter are not significantly different.**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

**Means with the same letter are not significantly different.**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV

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### DEPENDENT VARIABLE: COST

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### DEPENDENT VARIABLE: T

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### DEPENDENT VARIABLE: TV

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

Means with the same letter are not significantly different.

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

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### General Linear Models Procedure

#### Dependent Variable: COST

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**Dunnett's Multiple Range Test for Variable COST**

**Means with the same letter are not significantly different.**

**Alpha Level = .01**

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**Dunnett's Multiple Range Test for Variable T**

**Means with the same letter are not significantly different.**

**Alpha Level = .05**

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**Dunnett's Multiple Range Test for Variable TV**

**Means with the same letter are not significantly different.**

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*Model 1: TA0=50000 PLAN7=752 GECO1=1 PHONE2=2

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*Model 2: TA0=50000 PLAN7=752 GECO1=1 PHONE2=2

### DEPENDENT VARIABLE: TV

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*Model 3: TA0=50000 PLAN7=752 GECO1=1 PHONE2=2

### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

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### General Linear Models Procedure

**Dependent Variable: COST**

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### General Linear Models Procedure

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### General Linear Models Procedure

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### Means with the Same Letter are Not Significantly Different

**Duncan's Multiple Range Test for Variable COST**

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**Duncan's Multiple Range Test for Variable T**

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### General Linear Models Procedure

#### Dependent Variable: Cost

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#### Duncan's Multiple Range Test for Variable Cost

**Means with the Same Letter Are Not Significantly Different.**

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#### Duncan's Multiple Range Test for Variable TV

**Means with the Same Letter Are Not Significantly Different.**

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### DEPENDENT VARIABLE: COST

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### DEPENDENT VARIABLE: COST

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

### DEPENDENT VARIABLE: T

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

### DEPENDENT VARIABLE: TV

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV
### GENERAL LINEAR MODELS PROCEDURE

**DEPENDENT VARIABLE: COST**

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### GENERAL LINEAR MODELS PROCEDURE

**DEPENDENT VARIABLE: T**

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### GENERAL LINEAR MODELS PROCEDURE

**DEPENDENT VARIABLE: TV**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

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Means with the same letter are not significantly different.

### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

#### Groupings

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Means with the same letter are not significantly different.
### Table 1: General Linear Models Procedure (Cost)

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### Duncan's Multiple Range Test for Variable Cost

**Means with the same letter are not significantly different.**

**Alpha Level:** 0.01  
**DF:** 24  
**Rep:** 60

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### Duncan's Multiple Range Test for Variable T

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**Alpha Level:** 0.01  
**DF:** 24  
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### General Linear Models Procedure

**Dependent Variable: COST**

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**Contrast**

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**Dependent Variable: T**

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**Dependent Variable: TV**

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**Duncan's Multiple Range Test for Variable COST**

Means with the same letter are not significantly different.

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<th>STRUC</th>
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<td>D</td>
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**Duncan's Multiple Range Test for Variable TV**

Means with the same letter are not significantly different.

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### General Linear Models Procedure

**Dependent Variable: Cost**

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**Contrast**

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**Dependent Variable: T**

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**Duncan's Multiple Range Test for Variable Cost**

Means with the same letter are not significantly different.

**Alpha Level: .01**

**Grouping**

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**Duncan's Multiple Range Test for Variable T**

Means with the same letter are not significantly different.

**Alpha Level: .01**

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## General Linear Models Procedure

### Dependent Variable: Cost

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**Alpha** = 0.05

### Dependent Variable: T

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**Alpha** = 0.05

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**Alpha** = 0.05

### Duncan's Multiple Range Test for Variable Cost

**Means with the same letter are not significantly different.**

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<th>Struc</th>
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**Means with the same letter are not significantly different.**

### Duncan's Multiple Range Test for Variable T

**Means with the same letter are not significantly different.**

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**Means with the same letter are not significantly different.**

### Duncan's Multiple Range Test for Variable TV

**Means with the same letter are not significantly different.**

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### GENERAL LINEAR MODELS PROCEDURE

#### DEPENDENT VARIABLE: COST

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<th>C.V.</th>
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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

Means with the same letter are not significantly different.

#### ALPHA LEVEL: .01

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<td>C</td>
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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

Means with the same letter are not significantly different.

#### ALPHA LEVEL: .01

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### General Linear Models Procedure

#### Dependent Variable: COST

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<th>C.V.</th>
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<tbody>
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#### Dependent Variable: T

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#### Dependent Variable: TV

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<td>Model</td>
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### Duncan’s Multiple Range Test for Variable COST

Means with the same letter are not significantly different.

#### Duncan’s Multiple Range Test for Variable T

Means with the same letter are not significantly different.
### General Linear Models Procedure

#### Dependent Variable: Cost

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<tr>
<td>Model</td>
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<td>1.35311841</td>
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<tr>
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<tbody>
<tr>
<td>88.16182346</td>
<td>1629.84</td>
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#### Contrast

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### General Linear Models Procedure

#### Dependent Variable: TV

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<th>C.V.</th>
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<tr>
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<tr>
<td>91.41642160</td>
<td>199.99</td>
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### General Linear Models Procedure

#### Duncan's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

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### General Linear Models Procedure

#### Duncan's Multiple Range Test for Variable TV

Means with the same letter are not significantly different.

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### General Linear Models Procedure

#### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

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### General Linear Models Procedure

#### Duncan's Multiple Range Test for Variable TV

Means with the same letter are not significantly different.
### General Linear Models Procedure

#### Dependent Variable: COST

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#### Source

- **Type I SS**: F Value, Pr > F
- **Type IV SS**: F Value, Pr > F

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<th>DF</th>
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#### Dependent Variable: T

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- **Type I SS**: F Value, Pr > F
- **Type IV SS**: F Value, Pr > F

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<th>DF</th>
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<th>Pr &gt; F</th>
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<tr>
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<td>580.47</td>
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<td>PLET-ROC vs PLET-102</td>
<td>1</td>
<td>52.41938027</td>
<td>2448.73</td>
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#### Dependent Variable: TV

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<th>F Value</th>
<th>Pr &gt; F</th>
<th>R-Square</th>
<th>C.V.</th>
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</thead>
<tbody>
<tr>
<td>Model</td>
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<td>46.34613147</td>
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<td>24</td>
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#### Source

- **Type I SS**: F Value, Pr > F
- **Type IV SS**: F Value, Pr > F

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<th>Pr &gt; F</th>
<th>DF</th>
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#### Duncan's Multiple Range Test for Variable COST

**Means with the same letter are not significantly different.**

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</table>

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<th>N</th>
<th>Struc</th>
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</thead>
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<tr>
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<td>28.2848620</td>
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<td>B</td>
<td>27.8000000</td>
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<td>S</td>
</tr>
<tr>
<td>C</td>
<td>27.8000000</td>
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<tr>
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#### Duncan's Multiple Range Test for Variable T

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<th>Struc</th>
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<tr>
<td>B</td>
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<td>S</td>
</tr>
<tr>
<td>C</td>
<td>16.9900000</td>
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### Duncan's Multiple Range Test for Variable TV

**Means with the same letter are not significantly different.**

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<th>Struc</th>
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</thead>
<tbody>
<tr>
<td>A</td>
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### General Linear Models Procedure

**Dependent Variable: COST**

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<th>Source</th>
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<th>Mean Square</th>
<th>F Value</th>
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<th>R-Square</th>
<th>C.V.</th>
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<tbody>
<tr>
<td>Model</td>
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<td>62.75272703</td>
<td>12.5114351</td>
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<td>Error</td>
<td>24</td>
<td>0.2699449</td>
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**Dependent Variable: T**

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<th>C.V.</th>
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<tbody>
<tr>
<td>Model</td>
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<td>84.42799417</td>
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**Dependent Variable: TV**

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<tbody>
<tr>
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</table>

### Mean with the Same Letter Are Not Significantly Different

**Alphabetic Level: .01**

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<th>Struc</th>
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<tr>
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<td>23.090453</td>
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</tr>
<tr>
<td>C</td>
<td>23.614646</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>23.615825</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>E</td>
<td>23.954592</td>
<td>5</td>
<td>7</td>
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### Duncan's Multiple Range Test for Variable COST

**Alphabetic Level: .01**

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Mean</th>
<th>R</th>
<th>Struc</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>22.185451</td>
<td>5</td>
<td>0</td>
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<tr>
<td>B</td>
<td>23.090453</td>
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<td>C</td>
<td>23.614646</td>
<td>5</td>
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</tr>
<tr>
<td>D</td>
<td>23.615825</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>E</td>
<td>23.954592</td>
<td>5</td>
<td>7</td>
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</table>

### Mean with the Same Letter Are Not Significantly Different

| A        | 22.185451 | 5 | 0 |
| B        | 23.090453 | 5 | 4 |
| C        | 23.614646 | 5 | 5 |
| D        | 23.615825 | 5 | 6 |
| E        | 23.954592 | 5 | 7 |

**Duncan's Multiple Range Test for Variable T**

**Means with the Same Letter Are Not Significantly Different**

| A        | 22.185451 | 5 | 0 |
| B        | 23.090453 | 5 | 4 |
| C        | 23.614646 | 5 | 5 |
| D        | 23.615825 | 5 | 6 |
| E        | 23.954592 | 5 | 7 |

**Duncan's Multiple Range Test for Variable TV**

**Means with the Same Letter Are Not Significantly Different**

| A        | 22.185451 | 5 | 0 |
| B        | 23.090453 | 5 | 4 |
| C        | 23.614646 | 5 | 5 |
| D        | 23.615825 | 5 | 6 |
| E        | 23.954592 | 5 | 7 |
### General Linear Models Procedure

**Dependent Variable: T**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
<th>R-Square</th>
<th>C.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>17.17456213</td>
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**Contrast**

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<td>5</td>
<td>17.17456213</td>
<td>972.98</td>
<td>0.0001</td>
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</table>

**New=1064 TAO=256000 PLAN=AB2 GEOC=1 PRODS=8**

### General Linear Models Procedure

**Dependent Variable: TV**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
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<th>R-Square</th>
<th>C.V.</th>
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<td>0.17872841</td>
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**Contrast**

<table>
<thead>
<tr>
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<th>SS</th>
<th>F Value</th>
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<th>Pr &gt; F</th>
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</table>

**New=1064 TAO=256000 PLAN=AB2 GEOC=1 PRODS=8**

### Durban's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

**Alpha Level= .01**

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Mean</th>
<th>N</th>
<th>Struc</th>
</tr>
</thead>
<tbody>
<tr>
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<td>28.18245</td>
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<tr>
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<tr>
<td>F</td>
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### Durban's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

**Alpha Level= .01**

<table>
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<tr>
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<th>Mean</th>
<th>N</th>
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<tbody>
<tr>
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**New=9033234**
### GENERAL LINEAR MODELS PROCEDURE

#### DEPENDENT VARIABLE: COST

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<th>F VALUE</th>
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<th>R-SQUARE</th>
<th>C.V.</th>
</tr>
</thead>
<tbody>
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<td></td>
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#### DEPENDENT VARIABLE: T

<table>
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<tr>
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<th>F VALUE</th>
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<th>R-SQUARE</th>
<th>C.V.</th>
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</thead>
<tbody>
<tr>
<td>MODEL</td>
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<td>0.00093434</td>
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#### DEPENDENT VARIABLE: TV

<table>
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<th>PR &gt; F</th>
<th>R-SQUARE</th>
<th>C.V.</th>
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<tbody>
<tr>
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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

**Means with the same letter are not significantly different.**

<table>
<thead>
<tr>
<th>GROUPING</th>
<th>MEAN</th>
<th>N</th>
<th>STROOC</th>
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<tbody>
<tr>
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</tr>
<tr>
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</tr>
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<td>B</td>
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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

**Means with the same letter are not significantly different.**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV

**Means with the same letter are not significantly different.**

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**DEPENDENT VARIABLE: COST**

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<th>C.V.</th>
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**SOURCE**

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<td>1.92533333</td>
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**CONTRAST**

| PLT-ROC VS PLT-1DAY | 1  | 6.928582857    | 6.928582857 | 225.39  | 0.0001 |
| PLT-ROC VS PLT-4DAY | 1  | 6.928582857    | 6.928582857 | 225.39  | 0.0001 |
| USSE-ROC VS USEC-1DA | 1  | 0.01234567  | 0.01234567 | 225.39  | 0.0001 |
| USEC-ROC VS USEC-4DA | 1  | 0.01234567  | 0.01234567 | 225.39  | 0.0001 |
| PLT-ROC VS ALL OTHER | 1  | 9.625656666   | 9.625656666 | 225.39  | 0.0001 |
| PLA-CON VS ALL OTHER | 1  | 9.625656666   | 9.625656666 | 225.39  | 0.0001 |

**DEPENDENT VARIABLE: T**

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<th>R-SQUARE</th>
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<tr>
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<tr>
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<td>0.0001</td>
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<td>9.11728709</td>
<td>4391.58</td>
<td>0.0001</td>
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**CONTRAST**

| PLT-ROC VS PLT-1DAY | 1  | 0.671286123    | 0.671286123 | 225.39  | 0.0001 |
| PLT-ROC VS PLT-4DAY | 1  | 0.423456789    | 0.423456789 | 225.39  | 0.0001 |
| WESE-ROC VS WESE-1DA | 1  | 0.423456789    | 0.423456789 | 225.39  | 0.0001 |
| WESE-ROC VS WESE-4DA | 1  | 0.423456789    | 0.423456789 | 225.39  | 0.0001 |
| PLT-ROC VS ALL OTHER | 1  | 9.625656666   | 9.625656666 | 225.39  | 0.0001 |
| PLA-CON VS ALL OTHER | 1  | 9.625656666   | 9.625656666 | 225.39  | 0.0001 |

**DEPENDENT VARIABLE: TV**

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<tr>
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**SOURCE**

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<tbody>
<tr>
<td>TYPE I SE</td>
<td>5</td>
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<td>107.90</td>
<td>0.0001</td>
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**CONTRAST**

| PLT-ROC VS PLT-1DAY | 1  | 13.65265437    | 13.65265437 | 225.39  | 0.0001 |
| PLT-ROC VS PLT-4DAY | 1  | 9.730792654    | 9.730792654 | 225.39  | 0.0001 |
| USEC-ROC VS USEC-1DA | 1  | 0.94234567     | 0.94234567  | 225.39  | 0.0001 |
| USEC-ROC VS USEC-4DA | 1  | 2.34567890     | 2.34567890  | 225.39  | 0.0001 |
| PLT-ROC VS ALL OTHER | 1  | 5.67234567     | 5.67234567  | 225.39  | 0.0001 |
| PLA-CON VS ALL OTHER | 1  | 5.67234567     | 5.67234567  | 225.39  | 0.0001 |

**DUNCAN’S MULTIPLE RANGE TEST FOR VARIABLE COST**

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
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<th>STRUC</th>
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</thead>
<tbody>
<tr>
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<tr>
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**DUNCAN’S MULTIPLE RANGE TEST FOR VARIABLE T**

Means with the same letter are not significantly different.

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<td>C</td>
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**DUNCAN’S MULTIPLE RANGE TEST FOR VARIABLE TV**

Means with the same letter are not significantly different.

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### DEPENDENT VARIABLE: COST

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<th>R-Square</th>
<th>C.V.</th>
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<tbody>
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<td>Model</td>
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### DEPENDENT VARIABLE: T

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

**Means with the same letter are not significantly different.**

**Alpha Level:.01**

**Grouping**

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

**Means with the same letter are not significantly different.**

**Alpha Level:.01**

**Grouping**

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## General Linear Models Procedure

### Dependent Variable: COST

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<th>C.V.</th>
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### Contrasts

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### Dependent Variable: T

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### Contrasts

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### Means with the Same Letter are Not Significantly Different.

### Duncan’s Multiple Range Test for Variable T

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### DEPENDENT VARIABLE: COST

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### DEPENDENT VARIABLE: TV

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### DUNCAN’S MULTIPLE RANGE TEST FOR VARIABLE COST

Means with the same letter are not significantly different.

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### DUNCAN’S MULTIPLE RANGE TEST FOR VARIABLE T

Means with the same letter are not significantly different.

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### DUNCAN’S MULTIPLE RANGE TEST FOR VARIABLE TV

Means with the same letter are not significantly different.
### General Linear Models Procedure

#### Dependent Variable: COST

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### General Linear Models Procedure

#### Dependent Variable: T

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#### Dependent Variable: TV

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### Duncan's Multiple Range Test for Variable COST

Means with the same letter are not significantly different.

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### Duncan's Multiple Range Test for Variable T

Means with the same letter are not significantly different.

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### MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.
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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST

Means with the same letter are not significantly different.

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### DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T

Means with the same letter are not significantly different.

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### General Linear Models Procedure

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### Duncan's Multiple Range Test for Variable Cost

Means with the same letter are not significantly different.

**Alpha Level:** 0.01

**Alpha Level:** 0.05

### Duncan's Multiple Range Test for Variable TV

Means with the same letter are not significantly different.

**Alpha Level:** 0.01

**Alpha Level:** 0.05
### General Linear Models Procedure

**Dependent Variable: COST**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

Means with the same letter are not significantly different.

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

Means with the same letter are not significantly different.

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV**

Means with the same letter are not significantly different.

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### General Linear Models Procedure

#### Dependent Variable: Cost

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<th>C.V.</th>
<th>Cost Mean</th>
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#### General Linear Models Procedure

#### Dependent Variable: T

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#### General Linear Models Procedure

#### Dependent Variable: TV

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**Duncan's Multiple Range Test for Variable Cost**

Means with the same letter are not significantly different.

**Alpha Level:** 0.01

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<td>6.652600</td>
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<td>C</td>
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<td>D</td>
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**Duncan’s Multiple Range Test for Variable T**

Means with the same letter are not significantly different.

**Alpha Level:** 0.01

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<td>C</td>
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**Duncan’s Multiple Range Test for Variable TV**

Means with the same letter are not significantly different.

**Alpha Level:** 0.01

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<tr>
<td>B</td>
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<td>C</td>
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<td>E</td>
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### Dependent Variable: COST

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<th>C.V.</th>
</tr>
</thead>
<tbody>
<tr>
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<th>DF</th>
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### Dependent Variable: T

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<th>C.V.</th>
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<tbody>
<tr>
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### Dependent Variable: TV

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### Means with the Same Letter are Not Significantly Different.

#### Duncan's Multiple Range Test for Variable COST

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#### Means with the Same Letter are Not Significantly Different.

### Duncan's Multiple Range Test for Variable T

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#### Means with the Same Letter are Not Significantly Different.
### Table 1: General Linear Models Procedure

**Dependent Variable: CONT**

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<th>R-Square</th>
<th>C.V.</th>
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<th>Type IV SS</th>
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<td>27.99</td>
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**Duncan's Multiple Range Test for Variable COST**

Means with the same letter are not significantly different.

**Alpha Level: .01**

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**Duncan's Multiple Range Test for Variable TV**

Means with the same letter are not significantly different.

**Alpha Level: .01**

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**Duncan's Multiple Range Test for Variable TV**

Means with the same letter are not significantly different.

**Alpha Level: .01**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE COST**

Means with the same letter are not significantly different.

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE T**

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**DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TV**

Means with the same letter are not significantly different.

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APPENDIX I

REGRESSION ANALYSES
(Independent Variable: Cost)

1 - Total Data Set            ANOVA
2 - Total Data Set            Regression Coefficients
3 - Plant-0 Holding Days     ANOVA
4 - Plant-0 Holding Days     Regression Coefficients
5 - Plant-1 Day Holding     ANOVA
6 - Plant-1 Day Holding     Regression Coefficients
7 - Plant-4 Days Holding     ANOVA
8 - Plant-4 Days Holding     Regression Coefficients
9 - Warehouse-0 Holding Days ANOVA
10 - Warehouse-0 Holding Days Regression Coefficients
11 - Warehouse-1 Holding Day ANOVA
12 - Warehouse-1 Holding Day Regression Coefficients
13 - Warehouse-4 Holding Days ANOVA
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15 - Discriminant Data Set ANOVA
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17 - Total Data Set-7 Variables ANOVA
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## STATISTICAL ANALYSIS SYSTEM

**GENERAL LINEAR MODELS PROCEDURE**

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- PRODS
- GEONG
- TAD*PRODS
- TAD*GEONG
- TAD*PLANT
- PRODS*GEONG
- PRODS*PLANT
- GECOS*PLANT
- TAD*PRODS

**STD ERROR:**

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- 0.0446102
- 0.0434206
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**PR > (2-tailed):**

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- 0.0001
- 0.0001
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### F-Test for No Parameter

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### Statistical Analysis System

**General Linear Models Procedure**

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316
### General Linear Models Procedure

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- PR > F values indicate significance at the 0.05 level.
- C.V. refers to the coefficient of variation.
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**DEPENDENT VARIABLE: COST**

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**COST MEAN**

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**C.V.**

| MSE | 0.151496 |

**5% DEVIATION**