AN ANALYSIS OF FACTORS WHICH AFFECT LOAD VARIABILITY 
AND SYSTEM PERFORMANCE IN A MULTISTAGE, MULTIPRODUCT 
PRODUCTION SYSTEM 

DISSERTATION 

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By 

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***** 

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VITA

<table>
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<tr>
<th>Date</th>
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PUBLICATIONS


"A Reduced Search Heuristic for Solving the Multiple Criteria Lot Sizing Problem." Co-authored with Lee

FIELDS OF STUDY

Studies in Material Requirements Planning and Capacity Planning. Professor Larry Ritzman.

Studies in Production Planning and Scheduling. Professor Lee Krajewski.

# TABLE OF CONTENTS

ACKNOWLEDGEMENTS ........................................... ii
VITA ............................................................... iv
LIST OF TABLES .................................................. ix
LIST OF FIGURES ................................................ xii
LIST OF ABBREVIATIONS AND SYMBOLS ......................... xiv

Chapter

I. INTRODUCTION ............................................... 1
   1.1 Disaggregation in a Multistage Production System ... 4
   1.2 Factors Affecting Production Planning and Load Variability ............................................. 12
   1.3 Experimental Design Factors .......................... 19
   1.4 Research Questions and Overview .................... 20
   1.5 Scope, Assumptions, and Limitations of this Research ...................................................... 22
   1.6 Outline of Research Presentation .................... 24

II. REVIEW OF THE LITERATURE ................................ 26
   2.1 Priority Planning ........................................ 27
   2.2 Average Load on the System ........................... 31
   2.3 Magnitude of the Lot Size ............................. 35
   2.4 Product Structure (Bill-of-Material) ................. 39
   2.5 End Item Demand Variability .......................... 42
   2.6 Gateway Departments .................................... 45
   2.7 Degree of Work Center Specialization ............... 46
   2.8 Summary .................................................. 47

III. RESEARCH METHODOLOGY ................................ 49
   3.1 Research Factors ........................................ 50
       3.1.1 Number of Levels in the BOM .................... 50
       3.1.2 Average Shop Load ................................ 52
       3.1.3 Gateway ............................................. 53
       3.1.4 End Item Demand Variability ..................... 54
       3.1.5 Magnitude of the Lot Size ....................... 56
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2.8 Autocorrelation of the Weekly Loads</td>
<td>160</td>
</tr>
<tr>
<td>Across the Shop</td>
<td></td>
</tr>
<tr>
<td>4.3 Interrelationships of the Primary</td>
<td>165</td>
</tr>
<tr>
<td>Performance Measures</td>
<td></td>
</tr>
<tr>
<td>4.3.1 Factorial Discriminant Analysis</td>
<td>169</td>
</tr>
<tr>
<td>4.3.2 Correlation Analysis</td>
<td>170</td>
</tr>
<tr>
<td>4.4 Summary</td>
<td>174</td>
</tr>
<tr>
<td>V. SUMMARY AND CONCLUSIONS</td>
<td>184</td>
</tr>
<tr>
<td>5.1 Summary</td>
<td>185</td>
</tr>
<tr>
<td>5.2 Synthesis</td>
<td>191</td>
</tr>
<tr>
<td>5.3 Contributions and Limitations</td>
<td>196</td>
</tr>
<tr>
<td>5.4 Extensions</td>
<td>199</td>
</tr>
</tbody>
</table>

APPENDICES

A. MRPSIM Simulation Model                                              | 201  |
B. Bill-of-Material Generator                                           | 269  |
C. Sample BOM Inputs to MRPSIM                                          | 279  |
D. Research Design Members of Sample Experiment                        | 298  |
E. Results of Sample Experiment                                         | 301  |
F. Power Analysis of Sample Experiment                                  | 303  |
G. Results of Main Experiment                                           | 312  |
H. Power Analysis of Main Experiment                                    | 315  |
I. Sample FOQ and Discriminant Ranking Calculations                    | 323  |
J. ANOVA Results of Main Experiment                                    | 326  |
K. Means for Levels of Research Factors for Main Experiment            | 334  |
L. MANOVA Results                                                      | 346  |
M. Values of Parameters in Study                                       | 348  |

BIBLIOGRAPHY                                                            | 351  |
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Example of the Degree of Work Center Specialization</td>
<td>61</td>
</tr>
<tr>
<td>2. Example of Load Variability Measures Calculations</td>
<td>80</td>
</tr>
<tr>
<td>3. % Change in Power Between 2 and 3 Replications per Cell for the Sample Experiment</td>
<td>90</td>
</tr>
<tr>
<td>4. F-Ratio Values for the Sample Experiment</td>
<td>91</td>
</tr>
<tr>
<td>5. Means of the Main Effects For the Sample Experiment</td>
<td>92</td>
</tr>
<tr>
<td>6. Power Analysis For the Sample Experiment</td>
<td>93</td>
</tr>
<tr>
<td>7. Sample Size per Cell Needed For the Main Experiment</td>
<td>94</td>
</tr>
<tr>
<td>8. ( R^2 ) Comparison between the 7 and 5 Factor Fractional Factorial Experiment</td>
<td>108</td>
</tr>
<tr>
<td>9. MANOVA Results for Main Effects</td>
<td>120</td>
</tr>
<tr>
<td>10. Univariate F-Ratio, Components of Variance, and MANOVA Results for Interactions of the Research Factors</td>
<td>121</td>
</tr>
<tr>
<td>11. Means for all Levels of the Significant Interactions</td>
<td>122</td>
</tr>
<tr>
<td>12. F-Ratios and Components of Variance of the Main Effects</td>
<td>123</td>
</tr>
<tr>
<td>13. Power of the Test for the Main Effects</td>
<td>124</td>
</tr>
<tr>
<td>Table</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>14. Means for Each Level of the Main Effects</td>
<td>125</td>
</tr>
<tr>
<td>15. MANOVA-Standardized Discriminant Function Values for Main Experiment</td>
<td>167</td>
</tr>
<tr>
<td>16. Correlation Coefficients of Primary Performance Measures in Main Experiment</td>
<td>168</td>
</tr>
<tr>
<td>17. Comparison of Correlation Coefficients of Load Variability Measures</td>
<td>173</td>
</tr>
<tr>
<td>18. Summary of Statistics for the # of Levels in BOM</td>
<td>175</td>
</tr>
<tr>
<td>19. Summary of Statistics for the Degree of Work Center Specialization</td>
<td>176</td>
</tr>
<tr>
<td>20. Summary of Statistics for the Magnitude of the Lot Size</td>
<td>177</td>
</tr>
<tr>
<td>21. Summary of Statistics for End Item Demand Variability</td>
<td>178</td>
</tr>
<tr>
<td>22. Summary of Statistics for the Gateway Department</td>
<td>179</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Production Planning Hierarchy</td>
<td>5</td>
</tr>
<tr>
<td>2. Means of the Main Effects for Y1 - The Average</td>
<td></td>
</tr>
<tr>
<td>Cumulative End Item Backorders Performance Measure in Sample</td>
<td>98</td>
</tr>
<tr>
<td>Experiment</td>
<td></td>
</tr>
<tr>
<td>3. Means of the Main Effects for Y2 - The Average</td>
<td>98</td>
</tr>
<tr>
<td>Inventory Units per Average Item Performance Measure in Sample</td>
<td></td>
</tr>
<tr>
<td>Experiment</td>
<td></td>
</tr>
<tr>
<td>4. Means of the Main Effects for Y3 - The Average</td>
<td>100</td>
</tr>
<tr>
<td>Standard Deviation of the Load Summed over all Departments Performance</td>
<td></td>
</tr>
<tr>
<td>Measure</td>
<td></td>
</tr>
<tr>
<td>5. Means of the Main Effects for Y4 - The Auto-correlation of the</td>
<td>100</td>
</tr>
<tr>
<td>Weekly Loads Summed over all Departments Performance Measure</td>
<td></td>
</tr>
<tr>
<td>6. Means of the Main Effects for Y5 - The Average</td>
<td>102</td>
</tr>
<tr>
<td>Standard Deviation of the Load Across the Shop Performance Measure in</td>
<td></td>
</tr>
<tr>
<td>Sample Experiment</td>
<td></td>
</tr>
<tr>
<td>7. Means of the Main Effects for Y6 - The Auto-correlation of the</td>
<td>102</td>
</tr>
<tr>
<td>Weekly Loads Across the Shop Performance Measure in Sample Experiment</td>
<td></td>
</tr>
<tr>
<td>8. Means of the Main Effects for Y7 - The Average</td>
<td>104</td>
</tr>
<tr>
<td>Inventory Units Performance Measure in Sample Experiment</td>
<td></td>
</tr>
<tr>
<td>9. Means of LEVEL-LOT SIZE Interaction for Y1 - The Average Cumulative</td>
<td>131</td>
</tr>
<tr>
<td>End Item Backorders Performance Measure</td>
<td></td>
</tr>
<tr>
<td>10. Means of END ITEM - LOT SIZE Interaction for Y1 - The Average</td>
<td>133</td>
</tr>
<tr>
<td>Cumulative End Item Backorders Performance Measure</td>
<td></td>
</tr>
<tr>
<td>11. Means of Work Center Specialization - END ITEM Interaction for</td>
<td>135</td>
</tr>
<tr>
<td>Y1 - The Average Cumulative End Item Backorders Performance Measure</td>
<td></td>
</tr>
</tbody>
</table>
12. Means of Main Effects for Y1- The Average Cumulative End Item Backorders Performance Measure ................................. 136
13. Means of LEVEL-LOT SIZE Interaction for Y2- The Average Inventory Units per Average Item Performance Measure ....................... 139
14. Means of LEVEL-END ITEM Interaction for Y2- The Average Inventory Units per Average Item Performance Measure ................................. 142
15. Means of Main Effects for Y2- The Average Inventory Units per Average Item Performance Measure ................................. 142
16. Means of LEVEL-END ITEM Interaction for Y7- The Average Inventory Units Performance Measure ................................. 144
17. Means of Work Center Specialization-END ITEM Interaction for Y7- The Average Inventory Units Performance Measure ................................. 145
18. Means of Main Effects for Y7- The Average Inventory Units Performance Measure ................................. 146
19. Means of LEVEL-END ITEM Interaction for Y3- The Average Standard Deviation of the Load Summed Over All Departments Performance Measure ................................. 149
20. Means of Work Center Specialization-END ITEM Interaction for Y3- The Average Standard Deviation of the Load Summed Over All Departments Performance Measure ................................. 150
21. Means of END ITEM-LOT SIZE Interaction for Y3- The Average Standard Deviation of the Load Summed Over All Departments Performance Measure ................................. 152
22. Means of Main Effects for Y3- The Average Standard Deviation of the Load Summed Over All Departments Performance Measure ................................. 152
23. Means of Main Effects for Y4- The Autocorrelation of the Weekly Loads Summed Over All Departments Performance Measure ................................. 154
24. Means of END ITEM-LOT SIZE Interaction for Y4-The Autocorrelation of the Weekly Loads Summed Over All Departments Performance...... 155

25. Means of LEVEL-END ITEM Interaction for Y4-The Autocorrelation of the Weekly Loads Summed Over All Departments Performance Measure........... 155

26. Means of Work Center Specialization-END ITEM Interaction for Y4-The Autocorrelation of the Weekly Loads Summed Over All Departments Performance Measure.................. 156

27. Means of Main Effects for Y5-The Average Standard Deviation of the Load Across the Shop Performance Measure.................. 158

28. Means of END ITEM-LOT SIZE Interaction For Y5-The Average Standard Deviation of the Load Across The Shop Performance Measure........ 159

29. Means of Main Effects for Y6-The Autocorrelation of the Weekly Loads Across the Shop Performance Measure.................. 161

30. Means of END ITEM-LOT SIZE Interaction for Y6-The Autocorrelation of the Weekly Loads Across the Shop Performance Measure............. 162


32. Means of Work Center Specialization-END-ITEM Interaction for Y6-The Autocorrelation of the Weekly Loads Across the Shop Performance Measure......................... 164
LIST OF ABBREVIATIONS
AND SYMBOLS

LEVEL - the Number of levels in the BOM Factor.
ITEMS - the Degree of Work Center Specialization
LOT SIZE (or Lot) - the Magnitude of the Lot Size Factor.
END ITEM (or MPS) - the amount of END-ITEM Demand Variability Factor.
GATEWAY (or GATE) - the Gateway Department Factor.
RULE - the Priority Rule Factor.
LOAD - the Average Load on the System Factor.
Y1 - the Average Cumulative End Item Backorders Performance Measure.
Y2 - the Average Inventory Units per Average Item Performance Measure.
Y3 - the Average Standard Deviation of the Load Summed over all Departments Performance Measure.
Y4 - the Autocorrelation of the Weekly Loads Summed over all Departments Performance Measure.
Y5 - the Average Standard Deviation of the Load Across the Shop Performance Measure.
Y6 - the Autocorrelation of the Weekly Loads Across the Shop Performance Measure.
Y7 - the Average Inventory Units Performance Measure.
CHAPTER I
INTRODUCTION

The primary objective of this research is to identify and assess factors that can cause irregular loads in a multistage, multiproduct production system. Through a better understanding of these factors, better control of load levels can be achieved, and system performance improved. A secondary objective of this research will be to expand the MRP literature base, hopefully utilizing a more realistic set of research parameters than found in other studies, and clarifying the effects of these research factors so that future researchers in this area will be able to design their experiments accordingly.

In the area of production planning and control, much research has been performed in terms of the job shop system and job shop scheduling. Within the last decade, however, some of the research thrust has shifted to the area of Materials Requirements Planning (MRP). MRP is a planning technique relevant to multi-
product, multi-stage production-inventory systems.
While much has been written about MRP by various practitioners such as Orlicki [58], Plossl [62], and Wight and Plossl [76], the amount of published research is still small when compared to the job shop literature. The primary area of research pertaining to MRP has dealt with lot sizing techniques [9].

Also of interest has been the formalization of production planning into a planning hierarchy, usually called disaggregation, of which MRP is a major component [47]. Short term capacity planning is a part of this hierarchy, and deals with predicting and controlling the loads on the shop. Load profiles are generated from the MRP explosion so that the system's capacity can be adequately used and customer service goals can be attained. If the load on the system varies considerably from day to day or even week to week, excess costs will be incurred and the production planning system will not perform well overall.

For example, overtime and undertime costs, backordering and stockout costs, expediting costs, and inventory carrying costs will all increase if the load on the system is erratic. Consequently a relatively stable load over time is desirable in any multi-stage system. However, the average load in a production system could be stable, but capacity problems could still exist if bottlenecks occur in any one department thus causing other departments to be under-
utilized and creating a wide variance in the loads among the work centers in a production system. Therefore, achieving some stability in the loads at each individual work center is also an important consideration.

To date, research has centered on manipulating the loads at under or overloaded work centers over time so that the production goals could be met. The techniques of Adam and Surkis [1], and Schonberger [67], as well as finite loading, are examples of this type of reactive response to improperly balanced loads. While these techniques may be able to rebalance the loads, they have been criticized as being too complex or expensive to use in industrial settings. Instead of reacting to unbalanced loads, a better system of planning would be to stop them from occurring in the first place. Unfortunately, only in cases of deterministic forecasts is this even remotely possible. However, identifying and understanding what factors influence or cause irregular loads can lead to their control or manipulation by the production planner. Heretofore, very little research has been done on these factors, but it is the intent of this research to identify what factors are important in creating irregular or unmanageable loads in multi-stage, MRP oriented production systems. Several experimental factors will be examined to see how they affect various evaluation criteria pertinent to shop loading and multi-stage production systems.
An overview of hierarchical production planning in a MRP based system will be presented before these hypothetical factors and specific research questions are discussed.

1.1 Dissagregation in a Multistage Production System

Production planning and control in a multistage system is very complex and difficult to do. The primary reason for this is that there are multiple levels of planning, all of which are interrelated and somewhat interdependent upon one another. Also the time frames or planning horizons for the various levels overlap and intertwine, thereby compounding the overall planning procedure. Thus the planning procedure should ideally be approached as a total systems analysis comprised of feedback loops between the various planning levels, and not as a series of independent analyses. Figure 1 shows the various planning areas involved in a multi-stage production planning system and the flows of information between the areas. Similar planning systems have appeared in various American Production and Inventory Control Society articles [3]. The overall intent here is to satisfy customer orders by producing the required quantities of products (jobs) by some designated delivery time (due date) at the minimum possible cost. The following is a brief description of each of the planning areas.

1. Forecasting involves trying to predict the future demand on the system. In general, the forecasts
Figure 1

Production Planning Hierarchy
are for independent demand items, or finished goods. Recently, some research has been done by Plossl and Wight [76] in terms of keeping records of demand for dependent components, and forecasting for these parts. According to Plossl [62], extremely accurate, detailed, short range detailed forecasting will be practically impossible to achieve. In general, the demand forecast, in conjunction with on-hand orders, initiates the production planning process.

2. **Aggregate Planning (AP)** is a medium range planning device which attempts to determine the mix of medium range capacity expansion techniques in order to achieve various managerial objectives in the face of a fluctuating demand pattern. Aggregate planning involves the use of overtime, subcontracting, extra shifts, a variable work force, variable inventory levels, and backordering to meet monthly increases or decreases in aggregate demand on the system. It is based upon a fixed long range capacity level which is represented by a regular production rate for a normal work force size and set number of machines. Aggregate planning is thus a "rough" or "first cut" type of production plan for the system, which sets shipping schedules, inventory plans, and labor plans on an aggregate, or product family basis.

3. **Master Production Scheduling (MPS)** is a short range production plan which describes how much of each finished good is going to be produced for each future period
in the planning horizon. It describes the actual output levels that management wants to produce. The aggregate, or family demands, are broken down into individual item requirements. Then such factors as make to stock replenishment quantities, actual customer orders and backorders, customer service levels, and demand forecasts are utilized to derive the production schedule. In a MRP environment the planning horizon must be at least as long as the maximum cumulative production lead times for the products, and master production scheduling is usually done on a weekly basis. Therefore, each week a new schedule is generated detailing how much of each item to make for each week in the planning horizon, with the schedule for several of the closest weeks sometimes being "fixed" or non-changeable, in order to add stability to the planning process.

4. **Resources Requirements Planning (RRP)** is a technique which roughly checks to see if enough resources are available to meet the MPS's requirements. If resources are not available in sufficient quantity, then they must be increased or the MPS appropriately reduced. First, load profiles of important resources used in making a unit of a product are calculated for all of the company's products requiring them, and then, for each resource, resource profiles are generated based upon these load profiles and the appropriate quantities and timing supplied by the MPS for all products requiring that resource in the plan-
ning horizon. The quantities are derived using lot-for-lot logic, and do not take on hand inventory into account. If further resources are needed at any time in the horizon, appropriate action can be planned.

5. **Materials Requirements Planning** (MRP) is a computer based planning and data manipulation system for multi-stage production environments. There are two types of items, those for which demand is independent of the demand for any other items, and those for which demand is dependent upon the demands of other items. Independent demand is exhibited by end items or by products for which there are service demands. Dependent demand is exhibited by lower level items such as purchased raw materials, parts components, and sub-assemblies.

Material requirements planning time-phases product explosions so that lower level items are scheduled for production with the proper timing and quantities to meet the production schedules of higher level items.

In general, MRP generates planned order releases for all levels of production, based upon the MPS requirements for the finished products. These planned orders releases are then used to determine the daily production requirements for the system and become inputs to the capacity requirements planning stage.

6. **Capacity Requirements Planning** (CRP) uses the open orders already released and the planned order releases
generated by materials requirements planning to determine required rates of output by machine work center. Then the available capacity specified by the aggregate plan is adjusted as closely as possible to the production requirements of each time period in the planning horizon [48]. This process is sometimes called infinite loading, in that unlimited capacity is assumed when each work center's production load of jobs is tabulated for each time period in the planning horizon. However, capacity requirements planning does not directly manipulate the loading of the orders at the work centers, but attempts to project what capacity will actually be needed over the planning period [63]. Therefore, it takes the outputs from the MPS and MRP, calculates load profiles for each work center, and determines if sufficient capacity will be available to meet the planned production requirements. If sufficient capacity will not be available, there are several alternative courses of action that can be taken. The usual order of use, depending upon which of these options are available to a company, is:

a. revise the aggregate plan in order to increase short term capacity, i.e. work overtime, extra shifts, subcontract, shift workers from other departments, or add more workers if extra machinery is available.

b. use alternate routings of jobs in order to level the load among work centers.
c. revise the MPS by either releasing early or delaying the release dates of the jobs that are overloading the work centers, thus requiring a re-explosion of the MRP system to re-establish correct open and planned orders for component parts and assemblies [48].

d. revise the lot size of any orders causing under or overloads, as demonstrated by Harl [37]. Thus CRP involves feedback loops to the other planning areas and is necessary to insure that a feasible production plan is generated.

7. **Input-Output Control** is a technique for controlling actual capacity loads on the work centers. Each work center's planned load profile generated by the CRP is analyzed over the planning horizon in an effort to ensure that very little deviation from this planned load occurs in reality. In some sense, input-output control is similar to finite loading, however the techniques differ in methodology and complexity. The basic premise of input-output control is to not release more jobs to a work center than was indicated by the CRP (because this would increase the load, queues, and actual lead times associated with each work center) while still maintaining an efficient utilization of the production system. Therefore, planned versus actual inputs and outputs for the work centers are monitored to maintain a desired load.
8. **Priority Assignment and Scheduling**

involves the short range implementation of the production plan. Once the open orders have been scheduled for a given week and are released to the shop floor, queues will tend to form at each work center due to insufficient short-term capacity, or due to random fluctuations in the routing patterns. Some queuing is necessary to ensure an adequate utilization of the job shop facilities [42]; however, problems arise in attempting to determine the processing order for the job. In order to do this priorities must be assigned to the orders depending upon the relative importance of various goals, i.e. utilization of facilities, investment in work-in-process (W-I-P) inventory, or customer service. There are four main categories of rules: lateness rules, arrival order rules, job property rules, and random rules. None of these rules assure optimal assignment in conjunction with managerial goals, but do reflect various aspects of managerial policy.

In a machine-limited job shop the rule used may then be applied uniformly to all queues in the system to decide which order is to be processed next whenever a work center becomes available. The assignment of priorities is very important since it reflects the effectiveness of the shop in achieving managerial goals. A major problem with assigning priorities to orders in a queue is that the priorities may change over time. In a dynamic multi-stage environment orders are being revised and need dates may
change, primarily due either to customers changing their orders, or to insufficient lead time to make an order because of capacity limitations. These changes will be represented in the MPS and the MRP, and any priority assignment technique will have to be capable of handling these changes. Thus some orders may be assigned higher or lower priorities over time, depending upon the situation.

Thus the area of production planning and control is very complex and difficult to analyze, encompassing a great many areas of planning. All of these areas are interdependent and interrelated, and involve multiple feedback loops. The overall planning procedure is generally sequential; however, due to the feedback relationships a type of iterative analysis is recommended when doing any planning in a multi-stage, multi-product production system. It should be noted that not all companies would need such a complex planning and control system. However, most companies probably formally utilize several of these planning techniques, with informal use of the others.

1.2 Factors Affecting Production Planning and Load Variability

Many factors should be considered when engaging in multi-stage production planning. Some of these factors may directly or indirectly affect the production load on the system. The following is a brief description of some
of the more important factors.

1. **Information processing and updating systems** is a requirement for any detailed, accurate planning system. It is needed to keep track of the status of open orders in the system, as well as all other relevant information.

2. **Labor substitutability** is an aid in short term capacity manipulation.

3. **Costs and time estimates for equipment set-ups** are important because if the time requirements are large compared to the average processing time, and set-ups are frequent, then production backups could occur. Depending on what lot sizing technique is used, this may or may not cause load variability problems.

4. **Carrying costs of inventory** is a factor that is also related to the lot sizing technique, and usually influences managerial goals about the amount of inventory to have in any system.

5. **Planned and actual lead times** should on the average have equal values, but if planned lead time is substantially larger than actual lead time, a type of buffer stock is incorporated into the system. This tends to smooth out minor fluctuations in loads, but artificially increases the amount of open orders in the shop which could create inaccurate load profiles.

6. **Lot sizing** has a serious effect upon MRP and the amount of W-I-P inventory in the system. Depending upon
the lot sizing technique employed and the relative size of the production lots, the W-I-P queues at each work center will be directly affected, thus affecting the load at each work center.

7. **Priority rules** affect the order that jobs are processed at each work center and should have an effect upon load variability because they may hold an order that is going to a work-starved work center, or could hurry through an order that is going next to an overloaded work center. The reverse effect could also happen, and help to improve performance.

8. **The larger the number of operations per item** (component), the greater the likelihood of an open order being delayed in the shop since the order must enter more queues.

9. **End item demand characteristics** relationships' to load variability are unclear. The following items are represented or dealt with in the forecasting phase or MFS:

   a. **forecast error** - as this increases system nervousness should increase, possibly creating load variations.

   b. **seasonality and trend** - this should affect the overall load on the system, and could cause load fluctuations.

   c. **distribution and variance of demand** - as the patterns become more erratic or skewed the load levels may tend to fluctuate more. This is related to the stability in the MFS. Good MFS planning should help reduce the demand variability and
create a more stable input to the MRP system.

d. external orders for lower level items - if these are large and erratic then load fluctuations may occur, depending upon customer service policies.

10. As the number of end items increases various interactions could occur such as increased commonality, so that the amount of complexity increases, thus allowing the possibility of increased load variations.

11. Shop structure characteristics should have an effect upon load variability.

a. specialization of departments - here a department may do only one type of work, i.e. assembly only or fabrication only, or it may be able to do all types of work.

The first case could cause interdepartmental load variations if the mix of orders changes.

b. the number of work centers capable of doing an operation on an item - as the number of work centers capable of performing a particular operation on a particular item increases within a given department the load variation within that department should tend to decrease since that department becomes one large work center for that particular operation. This really represents specialization
of operations or items.
c. the number of items requiring a particular work center for a specific operation - this represents specialization of work centers. As the number of items that a work center can deal with increases, the possibility of load variation should decrease.
b. and c. assume a fixed number of machines per work center and parallel processing capabilities within each work center.

12. The routing of items through the shop can have a profound effect upon the shop loading patterns, since a poor routing scheme can overload or underload a work center.

13. A gateway department has most orders' routings originating in that department and overloads may occur in that department due to the mix of orders in the system, even if the capacity is increased. Also, underloads may tend to occur more frequently in downstream work centers.

14. Product structure characteristics' effects upon load variability are unclear.

a. the degree of commonality among items - as commonality increases for a given set of end items, dependent demand patterns become more stable, so this should tend to cause more stable loads. For a fixed number of items, as commonality decreases, the number and variety of component parts increases, thus increasing the systems complexity.
b. the number of components per parent - this represents the difference between linear assembly trees and broad multiple-component-per-parent product structures. As the number of components increases, the difficulty in meeting the parent's need date should increase, which could cause problems throughout the rest of the shop since the complexity and degree of interdependence of items in the bill-of-materials (B-O-M) is increased. There would also be a greater need for priority updating in this case which could effect load variability.

c. the number of times an item appears in the product structure - this would have a large effect upon the lot sizing logic.

d. the number of levels in the B-O-M - as the number of levels increases, the degree of complexity also increases. The cumulative production lead time could become longer which would allow the product to have an effect on the shop load for a longer period of time.

15. The use of safety stock in a MRP based system is somewhat questionable [58], but if proper quantities could be established and maintained in order to handle variations between planned and actual production requirements, then load variability should decrease as these fluctuations are buffered out by the safety stock.
16. As the complexity of routing increases from a very simplistic routing pattern, such as in a flow shop, to a more complex routing pattern, as in a job shop, load variability could be affected. A job shop routing should cause more load variance between the individual work centers than a flow shop routing due to the randomness of the routings and changes in the product mix over time.

17. As the average load on the shop changes the system should perform differently. If the shop is heavily over-loaded the system should perform poorly, and experience increases in work-in-process inventories. If the shop is highly under-loaded queues will be small at the work centers and system performance should be good. However, between these two extremes a range occurs wherein the system performance is not clearly predictable. Jones [43] has noted this, and stated that most researchers have somewhat arbitrarily picked a 90% load level for their studies. As the system becomes more overloaded, however, load variability should tend to decrease since queues would build at all work centers, thus making them always busy.

18. The purchasing of materials and parts could cause load variability problems if key parts are unavailable when needed, thus creating delays in those work centers.

19. Reworking materials or scrapping parts could cause load variability problems by creating delays while the parts are rebuilt or new parts are produced.
The previous discussion has considered various factors that might cause load variations or are important in a multistage production system. However, very little research has been published concerning this issue. Some factors should be more important than others, and certain factors interacting together may have differing effects under various circumstances. This research shall attempt to ascertain and analyze the relationships.

1.3 Experimental Design Factors

While all of the above factors may have some effect upon load variability, not all of them can be examined concurrently due to the complexity, size, and interdependencies among the factors. This research shall examine some of the more important managerially controllable factors. These factors are:

a. end item demand variability,
b. the number of levels in the B-O-M,
c. the concept of gateways,
d. the degree of work center specialization,
e. priority rules,
f. magnitude of the lot size, and
g. the average load on the system

While this may appear to be an unwieldy number of factors, the research methodology, using a fractional factorial design, eliminates some of these factors once some initial test runs are made. This is discussed in more detail in Chapter 3. Due to the complexity and
number of factors possibly affecting the results, some of the non-experimental factors will be randomized, and others fixed at certain levels so that a clearer understanding of the experimental factors can be achieved. The production system structure and explanation of which factors are so affected is discussed in Chapter 3.

1.4 Research Questions and Overview

This research attempts to answer the following general questions relating to the seven factors:

1. What effect, if any, does end item demand variability have upon shop load variability and system performance?

2. What effect, if any, does the number of levels in the B-O-M have upon shop load variability and system performance?

3. What effect, if any, does the average load have upon shop load variability and system performance?

4. What effect, if any, do gateways have upon shop load variability and system performance?

5. What effect, if any, does the degree of work center specialization have upon shop load variability and system performance?
6. What effect, if any, does the magnitude of the lot size have upon shop load variability and system performance?

7. What effect, if any, do priority rules have upon shop load variability and system performance?

8. What effect, if any, do combinations of the above factors have upon shop load variability and system performance?

Since some factors could cause erratic loads at various times, but with the system still performing well overall, some measure of system performance must also be included.

While little or no research has been published in this area, most previous research in multistage, MRP based systems has had several characteristics:

1. the evaluation involves very few end items in the product structure,
2. the evaluation uses very few levels in the B-O-M,
3. the evaluation is for very simple product structures in general, usually linear in nature,
4. the evaluation is relative to a single company, and may be distorted due to intervening variables and/or qualitative human factors, and
5. the evaluation involves simple shop structures.

This research shall attempt to address all of these limitations by creating a more realistic research environment. Hopefully by achieving this, more generalizable results will be attainable. The fourth characteristic will be addressed in a scientific manner via a general multi-stage, multi-product factory simulator, MRPSIM, which is a revised version of FACTORY V. Appendix A presents an overview of the simulator detailing its revised capabilities, as well as containing the program listing. By using the complex simulator, the objectives of this study should be attainable. All of the questions should be answered, as well as achieving more realistic, generalizable results.

1.5 Scope, Assumptions, and Limitations of this Research

The identification and analysis of factors that affect load variation and cause problems with system performance, as well as the expansion of knowledge in the area of production planning and MRP, are the primary points of interest in this study.

The distinguishing features of this study relative to past multi-stage, multi-product research are:

1. system performance is based upon average inventory units, backorders (representing customer service), and measures of load variation of all work centers in total and among the individual work centers,

2. the method of measuring load variation throughout the planning horizon,
3. a larger and more realistic product structure encompassing more levels and larger number of components,
4. a larger number of end items,
5. the complexity and realism of the system modeled should exceed previous research,
6. better control and manipulation of factors that could affect shop load and the MRP system in general,
7. through the use of test runs on the research factors, more factors can be analyzed via this research design, and
8. the first attempt to identify and analyze factors that can affect load variability.

Due to the above features of this study and the standardized logic of regenerative MRP the results of this research should have wide applicability. Hopefully, by analyzing these specific research variables the findings will be useful to practitioners in the field, especially with regard to designing their production system, since the parameterization of these variables is somewhat 'controllable' in this phase.

The assumptions of this study are: (1) purchased items are always available, (2) no rework or scrap in the system, (3) the shop is machine limited, (4) no safety stock, (5) no external orders for lower level components (6) there will be no forecast error, and demand will equal forecast plus backorders, (7) available machines and workers are always capable of working, (8) deter-
ministic processing and setup times, (9) no pre-emption or lot-splitting, (10) no alternative routings exist.

Assumption 1 and 2 assure this study of not having problems with materials or supplies and reduce the size of the experimental design.

Assumption 3 is necessary since shop structure is one of the research factors, however most production systems are labor limited.

Assumptions 4, 5, 6, 7, 8, 9 and 10 help to define the research setting. While variable processing and set-up times could in extreme cases cause load fluctuations due to jobs backing-up the system, this should not be a major problem, and usually would be uncontrollable.

These assumptions are made to facilitate this research, and may express some limitations of this study. However, future researchers can manipulate or relax these assumptions as appears necessary, thus creating more research topics within the area of production planning and control. One final limitation of this study is the problem of external validity as applied to any simulation study. Due to assumptions and complexities presented in this research, more realistic results than previous studies have achieved should be obtainable.

1.6 Outline of Research Presentation

In this chapter, a general description of the research topic and its relationship to the area of production planning and control in a multi-stage, multi-product system have
been described. Factors which could affect load variability, as well as specific experimental design factors, were then described. Finally, the objectives, scope, assumptions, distinguishing features, and limitations of this study were presented.

Chapter II presents a survey of the relevant literature in the areas of priority rules, lot sizing, material requirements planning, short term capacity planning, product structure, and shop structure. All of these topical areas are addressed in this study.

Chapter III provides a thorough description of the priority rules, lot sizing strategy, the nature of demand, the product structure, the shop structure, the cost structure, and performance measures, as well as description of the research design, hypotheses, and results of the initial fractional factorial analysis.

Chapter IV presents the research design, hypotheses, and findings of the full factorial research, including the statistical tests on the hypotheses. Chapter V summarizes the results and presents the major conclusions of this research. Also, all relevant observations and comments developed during this research, with special emphasis on the area of MRP, as well as suggestions for the future research uncovered during the study are presented.
CHAPTER II

REVIEW OF THE LITERATURE

The literature base for this research is diverse and represents a mixture of theoretical and pragmatic undertakings. Material requirements planning has been developed primarily by practitioners in the area of multi-stage production planning so that only recently have theoretically-oriented researchers become more involved in analyzing problem areas identified by the practitioners. This literature base is growing due to increased interest in production planning as well as the obvious need for sound research on such an important topic. Hopefully this study will enhance this literature base.

This review will focus on that portion of the production planning literature that is contiguous to the research area addressed in this study, and will endeavor to place this research in perspective within this body of literature. The following topics will be reviewed in this chapter: (1) priority planning, (2) the average load on the system, (3) lot sizing, (4) product structure (bills-
of-material), (5) end item demand variability, (6) gate-
way departments, and (7) the degree of work center special-
ization. This research represents only an initial attempt
to attain insight into the relationship between these
areas, load variability, and system performance. However,
due to the survey nature of this study the number of
published research articles relevant to several of
these topical areas is small.

2.1 Priority Planning

Most of the research involved with priority planning
and scheduling has involved job shop systems modeled and
examined by simulations. Several basic assumptions are
typically made, which have been noted by Gere (36).
These are:

1. the arrival times and processing times for each
   job are from prescribed probability density
   functions,
2. each job, once stated, must be performed to com-
   pletion, no pre-emption or order cancellations,
3. the job due dates are fixed,
4. the set-up times are included in the processing
times,
5. materials handling times between machines are
   negligible,
6. machines never break down and manpower of uniform
ability is always available,

7. machines are never able to perform a required task for lack of an operator, tool or material
8. no consecutive operations on the same machine for the same job,
9. no alternative routings are permitted,
10. no lap-phasing or lot splitting,
11. no overtime or subcontracting, and
12. no allowance for scrap or rework.

Various researchers have used some or all of these assumptions in order to simplify the study, but it should be evident that in a multistage setting, many of these assumptions are not legitimate.

Baker (4), Day and Hottenstein (27) and Krajewski (46) give good summaries of the methodology and research related to priority planning and scheduling. The following will be a brief survey of several articles in job shop priority planning, and will illustrate some of the approaches that have been used to examine the priority assignment problem.

One of the original studies of job shop priority rules was performed by Conway, Johnson and Maxwell (24) in which thirteen rules were analyzed in a simulated 5 machine job shop. Gere (36) initially analyzed the dynamic job shop, testing out several priority assignment rules. Since then, most job shop research has centered on this
setting. Nanot (52) also did a massive job shop simulation, again testing and evaluating the various priority assignment rules with regard to performance criteria. The last two studies assumed that the production facility was machine limited, that is, having some fixed production capacity due to the number of machines in the shop. A multistage environment was not assumed, and load on the system was not viewed as a significant factor. The results of these studies and others were often conflicting, depending upon what assumptions had been made about the job shop.

Hershauer and Ebert (41) attempted to develop a heuristic for assigning priorities that would perform well for multiple job shop evaluation criteria in all job shop environments. However, their procedure is so involved that practical applications may be unrealistic. Most recent research involves developing rules that will perform well for certain evaluation criteria. Berry and Finley (10), Berry and Rao (11), Surkis and Adam (69), and Carroll (18) all analyzed rules which would perform well according to some performance objective.

Another area of research concerns dual-constrained job shops, or shops that have limited labor and machine capacity. Nelson (54), (55) pioneered this work and analyzed what effect the dual-constrained system setting had upon the priority rules. Fryer (33), (34), continued this
analysis, also studying the effects of various shop sizes on the priority rules. Weeks and Fryer (74), (75) used the dual constrained setting to evaluate the assignment of due dates to jobs (orders) in the shop.

In the area of multi-stage evaluation of priority rules the amount of research is not as voluminous as for the single stage setting. Much of the work has concerned lot sizing's effects upon priority assignment. Berry (7) and Biggs (12) have analyzed this specific situation in depth. The work of Biggs is the most relevant to this research in that it utilized a previous version of the FACTORY simulator. Biggs found significant interactions between lot sizing techniques and priority rules. The studies involved a fixed product structure set, however, and did not consider the due date priority rule. The performance criteria were end item stockouts, lateness of end items, total number of setups, and average inventory value. Banerjee (5), (6), analyzed the importance of safety stock and priority rules in an MRP environment, utilizing the same simulation model, product structure demand pattern, and performance measures as Biggs. The research studied various safety stock policies and lot size/priority rule combinations under conditions of demand uncertainty. The priority rules were found to be a very significant factor relative to system performance.

The work of Biggs and Banerjee are very relevant to this
study, but there are significant differences. This research uses another priority rule not included in their research, has a much more generalized sample of product structures, utilizes almost entirely different performance criteria, has a much more complex and realistic shop structure and operating system, and addresses other factors in the experiment.

2.2 Average Load on the System

The effect of different average load levels upon system performance has generally not been studied. All research involving simulations of production systems have to assume some average load level or capacity utilization. However, most studies fix this parameter at some arbitrarily chosen level. Weeks and Fryer's (74), (75), studies of dual constrained job shops involved a 90% capacity utilization of labor, but gave no reasoning behind the choice of this capacity utilization level. Berry (8), utilized a variable load level per machine in his study of planned lead times and lot sizes, but the level was a function of the magnitude of the lot sized used.

Jones (43), approached the issue of capacity utilization in the job shop setting. In summary the article noted:

1. if there is too much work (load) in the shop or too little, any priority rule will perform well.
Most researchers have chosen the 90% load level,

2. the shop load level varies over time,

3. due to large queues at high load levels large
   amounts of computer storage are needed to model
   the system, thus discouraging research on this
   topic, and

4. the job arrival rate and work-in-process in-
   ventory levels affect shop load.

Jones analyzed the system in terms of cost factors,
but did not directly address the shop load problem,
especially in a multistage environment.

Deane and Moodie (28) also discussed the shop load
problem in terms of evaluation criteria for work load bal-
ancing. A heuristic was developed for assigning job prior-
ities based upon the effect that the job will have upon the
individual machine load, but the heuristic only indirectly
reacted to overloads and did not try to prevent them. No
mention was made of average load on the job shop.

Heard (39) analyzed the assignment of due dates based
upon surrogate shop load heuristics in a one machine pro-
duction shop, but again the average shop load for the system
was not even mentioned.

Conway, Maxwell, and Miller (25), analyzed three
priority rules (SPT, FCFS, and Slack/OPN) at three capacity
utilization levels in terms of % of jobs tardy. They con-
cluded that SPT performance is much less sensitive to variations in shop load than the other procedures, and that a strategy utilizing Slack/OPN during normal load situations and SPT during periods of overload would be best for minimizing the number of tardy jobs. An earlier article by Conway, Johnson, and Maxwell (24) also used three different load levels for analyzing priority rules in a job shop system. The load level had a significant effect upon average job lateness and work in process inventory dollars for the various priority rules. These two studies are significant to this research in that they utilized different load levels. However, both were for single stage systems and used different performance criteria.

Biggs and Hahn [15] analyzed the impact of capacity upon lot sizing decisions in a multistage production system utilizing the FACTORY II simulation model and the same system parameters Biggs had used in his other studies (see section 2.1). For several different load levels various lot sizing techniques were analyzed in terms of end item stockouts, number of setups, and the average dollar value of inventory. The study had several interesting conclusions:

1. the relationship between lot sizing techniques and capacity levels is not very significant,
2. end item stockouts and inventory levels are
positively correlated, and
(3) demand variability increases stockouts and inventory levels.

This article relates very well to the present research effort, but should be viewed in perspective to the differences between the present study and Biggs' earlier efforts, as described in Section 2.1.

Harl [37] developed and analyzed a capacity sensitive lot sizing algorithm in a study that is closely related to the present research. The algorithm modifies the lot size of any order that is causing overloads or underloads at work centers in the shop. The study also utilized a revised version of the FACTORY V simulation, and involved a multistage, multiproduct system. Seven research factors were studied in relationship to the algorithm, and the performance measures were the average end item backorders, total inventory cost, and the average work load variations. Three of the factors in the study, the number of levels in the BOM, the magnitude of the lot size, and the average worker utilization, are very similar to three of the factors in the present research, but have different treatment levels. Also, two of the performance measures, average end item backorders and average work load variation, are basically the same as two of the performance measures in the present study.
Harl found that for a utilization of 95%, average end item backorders, and total inventory costs were lower than for a utilization of 85%. There also was some interaction between the algorithm and this research factor.

2.3 Magnitude of the Lot Size

The literature abounds with articles on lot sizing. However, much of the existing lot sizing literature has not been adopted by practitioners. Krajewski [46] suggests that lot sizing models be categorized into two groups: independent lot models, and dependent lot models. Examples of independent lot models are Lot-For-Lot [58], Periodic Order Quantity (POQ) [9], Least Unit Cost (LUC), Least Total Cost (LTC) [58], Wagner-Whitin [73], Economic Order Quantity (EOQ) [38], and Fixed Order Quantity (FOQ) [58]. These models can generally be applied only to a single demand pattern. Examples of dependent lot models are Schussel's ELRS [68], Taha and Skeith [70], Crowston, Wagner, and Williams [26], Dhavale and Aggarwal [29], Berry [9], Callarman [16], and Napier and Steinberg [53]. These models derive a production plan whose sizing and timing decisions are dependent upon the sizing and timing decisions of other lots in the system. The distinguishing feature with this class of models is that the product structure becomes an important factor in the
final lot size decisions. Independent lot sizing models utilized in an MRP environment can also be viewed as dependent lot methodologies due to the effects of dependent demands between components in the product structure.

Lot sizing models can also be classified as static such as EOQ, or dynamic, such as Lot-For-Lot or Wagner-Whitin, depending upon whether the lot sizes vary from order to order. Fixed lot size models determine the lot size based upon a cost calculation, such as EOQ, or based upon a price break quantity, shipping size quantity, or physical limits upon inventory storage. The lot size is fixed in size from order to order until management reviews and decides to change it.

There have been many studies comparing lot sizing techniques' effects upon various performance criteria such as Kaimann [44], New [57], Berry [7], Biggs, Goodman, and Hardy [14], Biggs [12], [13], and Collier [21], [22] [23]. The latter articles involved MRP related studies and will be briefly discussed. Berry compared 4 independent lot sizing techniques using a single data base; inventory costs and ease of use were the performance criteria. The study found that a fixed EOQ which was an integer multiple of the average weekly demand would perform as well as the Wagner-Whitin algorithm in terms of inventory costs.
The present study utilizes this logic in determining the
FOQ for the end items.

Biggs, Goodman, and Hardy, used FACTORY II to evaluate
5 lot sizing techniques for a multiproduct, multicriteria
situation. The results show that EOQ was the best rule
for minimizing end item stockouts and the total number
of setups, but was worse for the average dollar value of
inventory. Biggs' studies are discussed in Section 2.1, but
in summary the studies drew the same general conclusions
about the EOQ technique.

Collier analyzed the selection of lot size factors
and where the items appeared in the product structures.
The study analyzed a small set of product structures in
terms of end item backorder, capacity utilization, setup
and inventory, and computer processing time performance. The
research factors were lot sizing techniques, end item demand
variability, and the degree of commonality in the product
structure.
The study noted that:

(1) the fixed EOQ model helped dampen system
nervousness and gave good performance for
the high demand variability and commonality
situations, and

(2) the fixed EOQ model represented a good com-
promise lot size strategy for multistage pro-
duction systems.
The studies by Biggs, Goodman, and Hardy, Biggs, and Collier are closely related to the present research. All of the studies used a simple product structure and some of the performance criteria were different from this study.

The previous studies highlighted the significance of using a fixed lot sizing strategy where multiproduct, multistage production systems are involved. Several other articles have advocated or utilized this strategy. Theisen (71) advocates using a fixed EOQ lot size for the end items in a multistage system. Plossl and Wight (63) advocate a FOQ lot size when "real-life" limitations influence the system. An American Production and Inventory Control (APICS) workshop on MRP (3) stated that most companies represented at the workshop used the FOQ lot sizing techniques. Klingman, Soland, and Ross (45) utilized a fixed group of lot sizes in their study of the effects of lot sizing upon machine loading. Ritzman, Krajewski, and Bragg (64) compared MRP and Order Point Systems using the revised FACTORY V simulation model. One aspect of the study analyzed the effects of small and large fixed EOQ's upon average inventory dollars and end items backorders. The study found that large lot sizes increased both inventory and backorder levels for the MRP and Order Point System. The study had only one basic product structure which was rearranged
to vary the number of levels in the BOM, however, so that the sample size may have been a problem.

Harl (37), as noted in Section 2.2., analyzed the effects of small and large fixed EOQ's upon three performance measures. The study found that for larger lot sizes (approximately 7 weeks worth of demand) the average end item backorders were lower than for smaller lot sizes (approximately 3 weeks worth of demand). Also, larger lot sizes tended to cause more work load variation.

2.4 Product Structure (Bill-of-Material)

In addition to being a parts list, the BOM defines the relationships between the end item and all component parts. Once item lead items and routing information are introduced the product structure defines the time periods and order that items are needed. Therefore the BOM has a direct impact upon the entire planning process.

Orlicky, Plossl, and Wight [59] noted the importance of the product structure to MRP and stated that:

The bill of material can and should be more than just part of the product specifications. It should also be viewed and used as a tool for planning.

The bill of material is expected to specify not only the composition of the product but also the process stages in that product's manufacture. The bill must define the product structure, in terms of so-called levels of manufacture, each of which represent the completion of a step in a building the product.
The product structure defines the relationship among the various items that make up the product in terms of levels, as well as the parent/component item relationships.

Thus the product structure is recognized as a key input to the MRP system.

Product structure is an important aspect of this study. Through the use of the BOM generator, (see Appendix B), a large sample of product structures can be produced which meet pre-specified characteristics of interest to this research. Of particular interest is the effect that the number of levels in the BOM have upon system performance and load variability.

The literature base dealing with the product structure is not very well developed. Most of the articles deal with software manipulation or implementation such as Campbell [17], and Wolfe [78], or with the concept of pegging, such as Orlicky [58], Peterson [60], Forrester, [32], and Herrick [40]. Orlicky [58], Garwood [35], Wight, Chobanian, and Zimmermann [77], New [56], and Carruthers [19] have discussed methods for designing bills of material and different formats that are in common use such as modular bills of material, indented formats, and group technology. Modularizing the bill of material has advantages in that there are:

1. a reduction in the number of bills of material,
2. a greater reduction in product structure records

3. a simplified index to the bills of material, and

4. simplified Master Production Scheduling.

Orlicki, Plossl, and Wight [59], discuss structuring the bill of material and one of the main points of the article is that bills of materials are not sacrosanct. They state the BOM can be restructured as long as the basic product specifications are unchanged. By redesigning or reassigning tasks, subassemblies and the number of items in the BOM can be changed to better identify unique parts or work to be done on a part. In summary, the authors seem to be saying that the design of the BOM is flexible and should be done so as to aid the MRP system.

None of the above articles, however, discuss what effects changes in the number of levels in the BOM would have upon the MRP system. The study by Ritzman, Krajewski, and Bragg [64] (see Section 2.3 for more details) also analyzed the effect that the number of levels in the BOM had upon average inventory dollars and end item backorders. Three different arrangements involving 1,3, or 5 levels in the BOM for one basic product structure were studied. However, due to differences in the costs of
subassemblies comparisons in terms of average inventory dollars are not possible between the 3 cases. Results in terms of backorders showed three levels in the BOM performed the best. This study was a forerunner of the present research, and several points of improvement should be noted.

The present research uses:

1. a different method of measuring inventories, so that different BOM's can be compared,
2. a much larger sample of BOM's, and
3. a better setting for the number of levels in the BOM based upon the survey by Anderson and Schroeder [2].

Harl (37) (see Section 2.2 for more details) also analyzed the effect that the number of levels in the BOM had upon three performance measures. In the first phase of the study, involving a fractional factorial research design, no significant relationship between this research factor, the performance measures, and Harl's lot sizing heuristic was found.

2.5 End Item Demand Variability

This research views the degree of end item demand variability as a surrogate for the effectiveness of master production scheduling techniques. Therefore, for this study if demand variability is high, the implication is that master
production scheduling has been ineffective in levelling demand. If demand variability is low, then supposedly better master production scheduling procedures were utilized to produce this lower variability. Orlicky (58), Maranka (50), and Malko (49) state several general criteria for successful master production scheduling.

1. It should be a plan for production, not an estimate or wish list.

2. It should be based upon requirements for end items or key component parts.

3. It is the main input to the rest of production system, and consequently affects the future loads on the system, inventory levels, and customer service.

4. Over the short horizon the MPS should be "firm" in that quantities of end items are committed to, and started in manufacture during this time.

5. When in conjunction with resource requirements planning, MPS determines the most realistic production schedule given the available resources of the company.

6. Do not "overstate" the MPS, that is, do not schedule more work than can possibly be performed over the planning horizon. Try to
smooth out the demand over time by techniques such as aggregate planning.

In general, MPS should tend to smooth out demand fluctuations on a week to week basis by making sure that capacity limitations are not being violated.

Several studies have analyzed the effects of end item demand variability in multistage systems. Berry [7] compared various lot sizing techniques under several different demand variability patterns. He concluded that demand variability had an effect upon the lot sizing rules in relation to their inventory costs performances. Callarman [16] analyzed the effects of demand variability and forecast error upon stockout costs using various lot sizing techniques and safety stock levels. He concluded that demand uncertainty had an effect upon the lot sizing rules in terms of backorder performance. Collier's work (21), the most relevant to the present research (See Section 2.3 for a discussion), concluded that demand variability had no significant effect upon end item backorders, setup costs, and inventory costs. However, end item demand variability had a significant effect upon overall planned load variability. The present study analyzes end item demand variabilities effects upon end item backorders, average in-
ventory units per average item, average inventory units, and several measures of actual load variability for a much larger sample of product structures.

2.6 Gateway Departments

The literature about gateway or inception departments is basically non-existent other than definition comments. The COPICS manual [42], and Plossl [61], however, mention some situations related to the idea of gateway departments. The basic point is that any department or work center with temporary recurring bottlenecks or overloads will cause overloads and underloads in work centers or departments downstream from the problem work center. In a random routed job shop the effects of a temporary overload in one department should be disseminated rather evenly throughout the shop. In a flow shop, which is what a gateway department partially creates, the effects of a temporary overload in the gateway department (which could be due to several large orders being released to that department simultaneously) should cause an overload to progress sequentially throughout the rest of the shop as the large orders are completed in each department.

This research shall try to expand knowledge about gateway departments so that production planners can see the effects of using gateway departments.
2.7 The Degree of Work Center Specialization

The literature pertaining to the degree of work center specialization in a multistage system is basically non-existent. The issue can be analyzed in two different ways. Assuming that a system has a fixed number of unique items in its product structure, then the degree of work center specialization can be changed by changing the number of work centers in the system, assuming a fixed number of workers in the system and fixed average load. The other method involves increasing the number of items and correspondingly decreasing the setup and operating times per item so that the total average amount of work remains the same in a system with a fixed number of work centers and workers. The first method actually analyzes the number of items per work center, whereas the second method analyzes the number of items per machine in a work center. The first method has been addressed in a job shop setting by Conway, Maxwell, and Miller (25). For the first method, by fixing the number of items, machines, and load when the number of work centers is increased (decreased), the number of machines per work center is decreased (increased). The authors have shown that as the number of machines per work center increases under the above assumptions the expected flow time per item will decrease somewhat. The present research analyzes the first method, the number of items per
work center, in a multistage system involving different performance criteria than were used by Conway, Maxwell, and Miller. Therefore, for this study the number of items per work center will be used as a surrogate for the degree of work center specialization. More items per work center represents less specialized work centers, and fewer items per work center represents more specialized work centers.

2.8 Summary

As short-term capacity problems become more severe, the effective performance of MRP systems should decrease. While there have been some attempts to overcome these capacity problems, very little work has been done to try to identify factors which cause these capacity problems. The objective of the research is to identify several of these factors so that production planners can institute better control over them and more properly design their manufacturing systems.

In this chapter the literature as it relates to the seven research factors is reviewed. Two of the areas, gateway departments and the number of items per department, have received very little attention in the literature. Very little work has been done with regards to MRP systems, and even less in terms of the objectives of this study. The articles that relate most closely to the present research are the works of Biggs [12], Collier
[21], [22], [23], Harl [37], and Ritzman, Krajewski, and Bragg [64]. However, in general for these studies either the research factors, performance measures, or simulation design were different from those in the present study. From this literature review it should be clear that much more research is needed in the area of MRP systems and short term capacity control. This study should clarify some questions and aid future researchers to better understand these two areas.
CHAPTER III

RESEARCH METHODOLOGY

This chapter presents the research factors and performance measures utilized in this study. The general research methodology and experimental design of the sample study is also discussed, as well as the simulation model and parameters. Finally, the results and analysis of the sample study, and design of the main experiment are discussed.

This research focuses on the evaluation and analysis of various factors that could have an effect upon shop load variability and system performance. As was previously noted, there has been very little research done in this specific area, and not very much research in general into MRP. A simulation model, MRPSIM, will be the research tool used in this study; it is described in Appendix A.

The scope of this research, as discussed in Chapter 1, is necessarily limited. The area of production planning in a multistage system is extremely complex and offers many alternative research topics. Presently the number of system parameters and decision variables, as well as inter-
dependent relations, is so large that a comprehensive analysis is impossible. Before the total system can be studied, the individual subsystem and relationships should be understood, which is one of the intents of this research.

This research focuses on two system characteristics (shop load variability and overall system performance) and seven factors (shop load, degree of work center specialization, priority rules, magnitude of the lot size, and demand stability) that could affect them given other various fixed system parameters (shop structure, product parameters, and cost structure). Overall system performance is determined by three measures of effectiveness: average cumulative end item backorders, average inventory units, and average inventory units per average item. Shop load variability is also determined by two measures: the standard deviation of the shop load and the autocorrelation of the weekly loads.

3.1 Research Factors

The following section describes how the various research factors are incorporated and defined in this study.

3.1.1 Number of Levels in the Bill of Material

Due to the design considerations, two levels are chosen. Products have either four levels (low) or eight levels (high), not counting the basic raw material. (The values in parentheses denote the treatment level of the
factor.) According to the MRP survey by Anderson (2), the average number of levels in most companies' products is six.

The larger the number of levels, the more complex the system should become, with increased coordination difficulty and more order releases. Also, in this study, the cumulative production lead time is positively correlated and confounded with the number of levels. Consequently, the product would have a longer time to affect the production system and shop loads, and could cause more load variability.

Several parameters are related to the number of levels in the BOM and, in order to perform this research, several assumptions and conditions have been made. In order to make comparisons between the two levels of this factor, in terms of the average inventory per item, this factor and the total number of items per product must be confounded. The average amount of commonality, the number of end items, and the average number of components per parent will be fixed at specific values throughout the experiments. Thus, the four-level case will have fewer items that the eight-level case, and certain corrections in terms of inventory costs will have to be made, as noted later in this chapter. Also, the labor efficiency will have to be changed between these two cases in order to
maintain the same machine loads. By making these assumptions some of the power and generalizability of the results may be lost, especially by confounding the number of levels in the BOM with the total number of items. However, while the importance of the total number of items in the system is unknown, it was considered to be the best parameter to confound with the number of levels in the BOM since confounding was necessary in order to not increase the research design. The number of items and number of levels are normally correlated, and since none of the dependent measures are directly related to the number of items, the confounding should not invalidate the results.

3.1.2 **Average Shop Load**

This factor can have any value from 0-100% of stated capacity. As stated in Chapter I, however, a range should exist wherein the actual average load, measured in terms of setup and processing time, has a significant effect upon sequencing rules, load variability, and the overall performance of the system. In an under or overloaded shop, the system should behave consistently good or bad, and these cases are not really interesting. In order to analyze this intermediate range, and due to design limitations, two average load levels of 85 (low) and 90 (high) percent are used. Jones (43) noted most job shop research used a 90% load level, and the 85% load level was
chosen to achieve a slightly less busy system. Labor efficiency, which affects both setup and processing times, will be utilized to attain the desired load levels. These values should be dispersed enough to allow for statistical comparisons, but still be within the aforementioned intermediate load range. Hypothetically, the 90% level should have less load variability than the 85% level since its machines should be busier and have larger queues on average.

3.1.3 **Gateway**

This factor will have two levels -- with a gateway department (high) or without a gateway department (low). A system with a gateway department should tend to have more load variability at the non-gateway departments, especially as the amount of work at the gateway department increases, since this will act as a bottleneck for jobs going to the other departments. The priority rule used at the gateway department also could have an effect on these relationships. In this study a gateway department is created by changing the routings for the first operation of each item while holding all other factors constant, such as the load per work center.

At lower load levels, the gateway may have no effect on load variability. However, these hypotheses may be incorrect due to interactions with various other research factors such as the magnitude of lot size and the number
of items per department.

3.1.4 End Item Demand Variability

This factor will have two levels: a stable demand pattern representing effective master production scheduling techniques (low), or an unstable demand pattern (high) which would occur if master production scheduling techniques were not used well. Therefore, the value of master production scheduling is being tested by this factor. The nature of demand can be divided into two elements: the degree of demand variability and demand uncertainty. A brief description of these demand characteristics will now be presented.

Kaimann (44), Berry (9), and Collier (21) utilized a method for describing the degree of demand variability called the coefficient of demand variation. The coefficient is described by Equation 1 below:

Coefficient of Demand Variation:

\[ C_V = \frac{\sigma_d}{\bar{d}} \quad (1) \]

where

\( \sigma_d = \) the standard deviation of weekly demand

\( \bar{d} = \) the average weekly demand

A high value for \( C_V \) would indicate large variability in the
size of the weekly demand. This would probably be more representative of a make-to-order end item, or certain replacement parts.

Demand uncertainty is associated with the probability distribution of forecast errors in any single period. If any forecast error is present, the demand is considered stochastic. The opposite case, or deterministic demand, will be utilized in this research due to difficulties in maintaining the average load and the need for reproducibility in various cells of the design. Also, Banerjee's (5) research suggests that the degree of uncertainty was not very significant on lot sizing and sequencing rules' effectiveness. However, this suggests an area for further research.

The level with a stable demand pattern for all end items will have a very low $C_V$ and be continuous, and will be a representation of effective master production scheduling at the end item level as well as what a make-to-stock demand pattern might appear as. The other level, having an unstable demand pattern, will have a higher $C_V$ and will represent the usage of poor master production scheduling, as well as what a make-to-order demand pattern might appear as. MRPSIM does not have a sophisticated MPS subroutine, so that variability in the forecasts must be utilized to represent this factor.
In order to make intercell comparisons of the dependent variables, all of the simulation runs must have the same total demand. Consequently, the demand patterns will be generated from two distributions: a negative exponential function for the interarrival time of the demand and a normal distribution for the quantity of the demand. The same number seeds for the random number generator will be kept throughout each replication of the experiment, thus ensuring the same total demand for all cells in each replication. Also, each end item will have the same average demand in order to allow each to have equal effects on the system, but will have slightly different variances for greater variety.

As MPS instability increases the system should experience more load variability and poorer performance.

3.1.5 Magnitude of the Lot Size

This factor will have two levels based upon Fixed Order Quantity (FOQ) logic: an end item lot size approximately equal to the average demand in a two-week period (low), and an end item lot size approximately equal to the average demand in a four-week period (high). These values were arbitrarily chosen in order to sufficiently demonstrate performance differences, if any should exist, and to still be as realistic as possible.

The magnitude of the lot size and demand variability
are closely related since the lot size can dampen or smooth out end item demand variations. Consequently, in the one end item case, large lot sizes should decrease load variability due to a leveling effect on the order releases if demand variability is high. When demand variability is low a large lot size should create "lumpiness" and increase load variability. However, when there are more end items in the system, larger lot sizes may increase the load variability due to more "lumpiness", but the combined effects of so many end items may also cancel out each other.

For each end item, an initial Economic Order Quantity (EOQ) calculation is performed using a constant setup cost, the holding costs for the end item, and the yearly demand. Then for the low level of the factor the EOQ value is multiplied by two to arrive at an FOQ. For the high level of the factor the EOQ value is multiplied by 4 to arrive at an FOQ. Then for each component the same calculations will be performed, using the appropriate holding costs, to determine their EOQ value. This EOQ value will then be rounded to the nearest integer multiple of its parent's FOQ. The high level of this factor thus has an average FOQ twice as large as the low level of this factor. The raw material will utilize lot-for-lot logic in the simulation. For any common parts the parent with the largest FOQ will
be used for the integer multiple calculations. Example calculations are in Appendix I. In order to better implement the MPS, the lot-for-lot rule will also be used on the end items so that any variability is passed onto the lower level items. EOQ and FOQ calculations for the end items, therefore, are only used to start the integer multiple procedure for the components and are not used in the daily planning and operations of the simulated shop.

3.1.6 **Priority Rules**

As noted in Chapter II, the literature abounds with studies of sequencing on priority rules in single stage environment, and some work has been done by Berry (7) and others in multistage systems. Hundreds of heuristics have been proposed and tested, with the most frequently mentioned rules being: shortest processing time first (SPT); critical ratio (CR); earliest due date (DD); first come first served (FCFS); and dynamic slack (DS). These rules exhibit certain documented characteristics in job shop environments, but their performances in multistage systems are presently unclear, due to the interdependencies of the items in the system and the lack of research.

Due to the simulation aspects of this research and the large number of research factors, the number of levels of each factor had to be limited to two. Therefore, only two priority rules could be studied. SPT (low) was chosen
as one level because it is generally considered to be one of the better rules in the job shop literature, and the best for average flow time. Also, SPT tends to get the highest number of jobs through a machine center and keeps the larger jobs in queue longer. Because SPT uses a measure of a job's share of the machine load as its decision criterion, load variability could be affected by its use. Since the queue is composed primarily of larger jobs which tend to stay in queue longer and would stabilize the average load, load variability may be smaller than with other rules. However, due to the interdependencies of the open orders (jobs) and thus the machine queues in a multi-stage system, the specific nature of any effect SPT could have on load variability is unclear.

The Due Date rule (high) was chosen as the other level for this factor because of its use by many practitioners in companies with multi-stage systems. Since DD's decision criteria is not directly related to shop load, as with SPT, its queue size and load should be more variable. Also, by manipulating order due dates, load variability can be somewhat controlled by management, but this will not be done in this study.

3.1.7 Degree of Work Center Specialization

This factor has two levels dictated by the number of
departments in the system: four (high) or eight (low) departments, with each department having one work center. Therefore, one level will have twice as many items processed through a department, given the same total number of items and operations. Consequently, for any set of BOM's the routings will be adjusted when the number of departments change so that the same average ratio of work between the departments is maintained, as illustrated in Table 1. Also, the labor efficiency will be manually adjusted to maintain the same average load levels through a series of trial simulation runs.

As the number of items per department decreases, the amount of load variation should increase due to increasing specialization of work centers (departments). However, this result could be influenced by the average load on the system and the magnitude of the lot size.

3.1.8 Summary

Due to the large number of factors and the complexity of the interrelationships involved in this research area, definitive alternative hypotheses concerning the effects of these factors on the dependent variables are difficult to make.

Furthermore, some of the interactions between the factors may also be important, as has been previously mentioned. By analyzing these factors at their stated
Table 1

Example of Degree of Work Center Specialization

<table>
<thead>
<tr>
<th>4 Departments</th>
<th>8 Departments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 or 2</td>
</tr>
<tr>
<td>2</td>
<td>3 or 4</td>
</tr>
<tr>
<td>3</td>
<td>5 or 6</td>
</tr>
<tr>
<td>4</td>
<td>7 or 8</td>
</tr>
</tbody>
</table>

as we go from 4 to 8 departments, each operation is randomly assigned one of the two possible numbers

<table>
<thead>
<tr>
<th>Item</th>
<th>Routing</th>
<th>Operation</th>
<th>Time/Item</th>
<th>Item</th>
<th>Routing</th>
<th>Operation</th>
<th>Time/Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>14</td>
<td>1</td>
<td>3</td>
<td>14</td>
<td>1</td>
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<td>12</td>
<td>6</td>
<td>4</td>
<td>8</td>
<td>8</td>
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<tr>
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<td>8</td>
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<td>3</td>
<td>11</td>
<td>3</td>
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<td>2</td>
<td>4</td>
<td>4</td>
<td>20</td>
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<tr>
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<td>3</td>
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<td>8</td>
<td>7</td>
<td>8</td>
<td>9</td>
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</tr>
</tbody>
</table>

* Items Processed by Each Department

<table>
<thead>
<tr>
<th>Department</th>
<th>4 Departments</th>
<th>8 Departments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>3</td>
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<tr>
<td>2</td>
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<tr>
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<tr>
<td>7</td>
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<td>3</td>
</tr>
<tr>
<td>8</td>
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<td>3</td>
</tr>
</tbody>
</table>
levels, hopefully some of the relationships will be clarified sufficiently to enable better hypotheses in future research.

3.2 Fixed and Randomized Factors

The previous section detailed the seven research factors that were analyzed in this study. They are set at one of their two possible treatment levels for any given experimental run. Due to the complex nature of the simulation there are numerous other factors that were either fixed at one level or randomized. These other factors, therefore, serve to establish the experimental setting, or in this case, attempt to create as realistic and generalizable a representation of a manufacturing environment as possible. The following sections describe all of the factors or parameters which are present in this simulation study, specifying what values each level of a factor is set, and any other factors they are confounded with. A summary of all the research factors and parameter settings is given in Appendix M.

3.2.1 Product Structure

The logic of MRP is based upon knowledge of the product structure (BOM) of all end items produced by the system. The demand for any item (component) in the system is dependent upon the production requirements for its parent(s). Consequently, the product structure plays a
crucial role in defining these parent/component relationships and the operation of any MRP planning system. Unfortunately, as noted in Chapter II, very little is known about what effect any changes in product structure design would have upon MRP and the production system in general. Most research instead has centered upon operating characteristics of the items comprising the BOM.

The following brief summary of product structure parameters can be placed into two main categories: physical design aspects which describe the arrangement and relationships of items comprising the finished goods; and operating information which deals with the specifics of the planning and shop floor manufacture of each item. Most of these parameters are self-explanatory or have been mentioned elsewhere. The physical design parameters and their values for each experimental run are:

1. number of end items—fixed at four end items per run,
2. total number of items—randomly generated, with a range of 20-200,
3. number of levels in the BOM fixed at four or eight per run,
4. number of parents per component, or the degree of commonality—fixed at approximately 20% of components having two parents, 40% having one parent, and the
5. number of components per parent—uniformly randomly generated, with values of 0, 1 or 2. If 0, the item is a purchased part.
The operating parameters are:

(1) number of operations per item is uniformly randomly generated, with values of 1, 2 or 3,

(2) routing of each item from operation to operation is uniformly randomly generated, except for when gateway department is used,

(3) planned lead time for each item is fixed as a function of the setup time, plus the processing time multiplied by the lot size, plus a constant for estimated queue time,

(4) setup time per operation per batch is randomly generated by level in the product structure so that, as the components become lower in the BOM, the setup times increase due to more complex operations and tasks, and to allow for large lot sizes, and the

(5) processing time per operation per item is randomly generated as a percentage of the setup time with $N (.03, .02)$.

All of these parameters must be specified in order to operate any MRP or production planning system, and comprise the product structure information needed for the MRPSIM simulator.

In order to make this study as generalizable as possible, a large sample of product structures would be necessary, involving an exorbitant number of simulation runs, as well as the cooperation of many companies willing to divulge proprietary product structure information. Consequently, a BOM generator has been developed that is capable of randomly generating from any desired distribution all of the product structure issues previously described. Therefore, a variety of product structures can be
sampled, as well as random replications of these product structures. A description of the BOM generator appears in Appendix B.

3.2.2 Shop Structure

The MRPSIM simulator can model a wide range of shop configurations, from a unidirectional flow shop to a random routed job shop. In this study the shop configuration is related to two of the research factors: the number of items per department, and the use of a gateway department. Initially, the system will be modeled as a random routed job shop with four departments, and will be changed depending upon what cell of the design is being analyzed. Each department will have one machine group so that the routing will be interdepartmental, not intradepartmental. The number of machines and laborers per machine group, as well as their efficiency, are a function of the product structure and will vary from cell to cell as the number of levels in the BOM, the number of departments and the use of a gateway department change.

The priority rules are also part of the design, but in the event of a tie the First In First Out rule is used. Because demand is deterministic and a regenerative MRP system is used, the due dates per item are static.

The shop structure parameters will also be determined by the BOM generator, and are included, along with the product structure data, as input data to the simulator.
3.2.3 Cost Structure

The cost structure for this research primarily consists of inventory and setup costs for each item in the BOM. Since the product structure is randomly generated for each BOM, and due to the nature of the inventory cost calculations per item, comparisons of performance criteria involving costs is of questionable validity and has not been included in this study. Setup costs will be assumed at a constant value of $1 per minute of setup time per item. The only reasons for including setup and inventory costs is for the calculation of the EOQ and subsequent FOQ for each item. The inventory carrying cost is set at a constant 25% of inventory dollar value. The value of each inventory item can be derived by establishing a purchase price for the raw materials that go into higher level component parts. Then, by proceeding up the product structure, values per item can be computed by summing up the value of component parts. The cost of labor is not included since companies have different pay structures, and cost is not used in the performance measures. In order to achieve more generalizability, the value of the raw materials will be randomized in the BOM generator so that multiple cost structures can be obtained.

3.3 Simulation Information

The simulation model generates a new forecast every
week as the planning horizon is developed. The forecast planning horizon is 52 weeks out from the current week, so that if it is currently week 100, the forecast is for weeks 101 through 151. MRPSIM is based upon a regenerative MRP system, and any orders already released to the shop are maintained through each regeneration. The actual demand for the end items is the sum of the forecast plus any backorders from the previous week. Once an open order for an item requiring component parts is completed, it is placed into work-in-process inventory until it is needed by its parent. However, if not enough components are available to fill a required open order at its due date, a smaller order can be released. This smaller quantity is regulated by a minimum release size parameter. In this research the minimum release size will be 90% of the normal lot size. Thus if a normal lot size is 100 units for a parent, the order will be released if 90 or more of each component part are available at the due date. This parameter could have an effect upon the lot sizing factor. However, the use of a 90% value should cause only minor perturbations. Backorders should be somewhat smaller than normal, but the use of this parameter should make the system more realistic since companies in some industries have scrap losses and shrinkage in their systems.

In this research the simulation model was run for
350 weeks (1750 days), with performance data collected (the recording period) over the last 250 weeks (1250 days) and an initialization period of 100 weeks (500 days). Appendix A discusses the issues of establishing initial conditions and determining when the simulation exhibits steady state characteristics.

The following is a list of assumptions and conditions utilized in MRPSIM and this research:

1. raw material is always available,
2. the average demand per end item is 100 units per week. If there is demand variability, the C_v is normally distributed with mean of 1 and standard deviation of .02, with a seasonal pattern between 3 and 9 weeks,
3. jobs in departmental queues are assigned to the first machine and worker available,
4. no alternate routings exist,
5. there is one 8 hour shift operating 5 days per week,
6. there is no planned safety stock for any item,
7. the beginning inventory is normally distributed in multiples of the lot size, with a standard deviation of 1 multiple of the lot size, and
8. the backorder performance in this study may be higher than experienced in industry due to the fact that no expediting of orders or re-planning decisions are being made.

3.4 Performance Measures

Several of the dependent variable performance measures employed in this research have been developed
specifically for the problem being studied and have proven very useful in evaluating the independent research variables. The main objectives of using the seven primary performance criteria are to detect load variance and measure system performance. If a research factor affects both load variation and system performance, the factor would play an important role in production planning. A secondary objective is to evaluate the correlation between system performance and load variability. A third objective is to determine if overall shop load variability measures are better predictors of system performance and load problems than individual work center load variability measures.

The seven primary dependent variables will be discussed first, followed by an abbreviated presentation of all secondary performance measures.

3.4.1 **Primary Performance Measures**

The seven primary performance measures are (1) average cumulative end item backorders, (2) average inventory units per item, (3) average inventory units, (4) average standard deviation of the load summed over all departments, (5) average standard deviation of the load across the shop, (6) autocorrelation of the weekly loads summed over all departments, and (7) autocorrelation of the weekly loads across the shop. Each of these
measures will be discussed briefly.

3.4.1.1 System Performance Measures

**Average Cumulative End Item Backorders - Y**

The cumulative end item backorders is an important measure of system performance. The objectives relative to backorder performance are to maintain at least a minimum level of competitive customer service so that the lower the amount of backorders, the better these objectives are met.

The measure is the sum of the average of all end item backorders over the recording period of 250 weeks (1250 days).

The equation is:

\[
Y_l = \frac{1}{250} \sum_{t=1}^{250} \sum_{i=1}^{4} B_{i t}
\]

(2)

where

\[B_{i t} = \text{end item backorders for product } i \text{ in week } t.\]

Simply summing the average backorders is valid, since all end items have the same average demand. The simulation continually attempts to fill past backorders.
Average Inventory Units per average Item $Y_2$

For each BOM new product structures and raw materials costs are generated so that inventory cost can not be used for comparison of system performance, as has been previously done by Biggs [12], and Berry [9]. Biggs and Hahn [15] noted this same difficulty in their study. The average number of units in inventory averaged over all items in the BOM throughout the planning horizon represents a system performance measure.

The equation is:

$$Y_2 = \frac{\sum_{i=1}^{M} \sum_{t=1}^{250} I_{it}}{(250)(M)}$$

where

$$I_{it} = \text{total inventory units for product } i \text{ in week } t.$$  

$M = \text{the number of items in the BOM.}$

A managerial objective would be to minimize the value of this measure, while still maintaining satisfactory customer service, in order to keep inventory carrying costs as low as possible.
Average Inventory Units - Y7

In this research the number of items in the BOM and the number of levels in the BOM are confounded. Generally, as the number of levels increase, so do the number of items. The average inventory units per average item (Y2) corrects for this confounding. However, the average inventory units for the BOM is still of interest. A BOM with many items would usually have more average inventory than a BOM with fewer items. Therefore the average inventory units is included as a system performance measure but is confounded with the number of levels in the BOM factor. The equation is:

\[ Y7 = \frac{\sum_{t=1}^{250} \sum_{i=1}^{M} I_{it}}{250} = (Y2)(M) \] (4)

where

\( I_{it} = \text{total inventory units for item i in week t.} \)

\( M = \text{the number of items in the BOM.} \)
3.4.1.2 **Load Variability Performance Measures**

This research focuses upon load and load variability, which are measured relative to the stated capacity. Several techniques are available for manipulating or planning loads, such as finite capacity planning and capacity requirements planning. As previously stated, this research is concerned with actual load and load variability on a week to week basis. One of the experimental design factors is average load level, and four of the dependent variables deal with weekly load variations.

The two load related issues are concerned with the weekly load variability summed over all departments, and the average load variability in the whole job shop. By looking at these two issues and comparing them to the system performance evaluation criteria, the following relationships can be analyzed. First, what is the relationship between individual department's load variation and load variation measured over the entire shop? Secondly, what is the significance of the relationships of individual department's load variability and shop load variability to the system performance dependent variables? Possibly shop load variability has a more important effect on the system performance variables than the variability at each department. Possibly, the load variability at one department is causing many problems, and the job shop or routings
can be redesigned to eliminate this situation.

**Average Standard Deviation of the Load Summed over all Departments - Y3**

The first load measuring device is the average standard deviation of the load summed over all departments. The load is measured at the end of the week in terms of orders completed, work in queue, and work in process on the machine. Large load deviations should be more harmful than small deviations due to a lower likelihood of the shop being able to cope with large deviations. Therefore, the standard deviation, which highlights large deviations, was chosen instead of the mean absolute deviation for this measuring device, as well as the average standard deviation of the load across the entire shop. The equation is:

\[
Y3 = \frac{G}{\sum_{g=1}^{G} \left( \frac{\sum_{t=1}^{T} (E_g - L_{gt})^2}{249} \right)^{1/2}}
\]

(5)

where

- \( \overline{E}_g \) = average load over the horizon for department \( g \).
- \( L_{gt} \) = load in week \( t \) for department \( g \).
- \( G \) = the number of departments.
The objective of this measure is to have values as close to zero as possible, so that no extra operating costs would be incurred, such as overtime or expediting costs.

**Autocorrelation of the Weekly Loads Summed over all Departments - Y4**

This measure (Y4) and the autocorrelation of the weekly loads across the shop analyze the length and severity of periods of underloads or overloads. In order to measure the length of these periods a benchmark, or planned average load level, from which to calculate underloads or overloads must be known. In this research the planned average load is a research factor which is fixed at either 85% or 90% of capacity. Ideally, deviations from the planned load should be small, and any periods of large underload or overload should be as short as possible so that production goals can be attained. Even if the average load over the horizon equals the planned load, long periods of alternating large underloads and overloads could be damaging since adjustments may not be made quickly due to overtime limits or cash flow problems. However, alternating short periods of underloads and overloads may not create any problem.

Autocorrelation normally measures the correlations existing between a time series of observations spaced by
a constant interval of time. Computed over a number of consecutive observations, M, each separated by a constant time period, K, the autocorrelation measures the change from period to period of the difference between a predicted and an observed value for a variable. If the autocorrelation is positive, then each of the n observations is positively correlated with the next observation in the time series. For example if a positive autocorrelation exists, and if period n's observed value is above the predicted, then period n+1's observed values should tend to be above the predicted value, too. In this study a surrogate for autocorrelation is used that reflects the absolute magnitudes and the length of periods of underloads and overloads. The surrogate measures the absolute sum from week to week of the difference between the average planned load and the actual load. The surrogate is called the autocorrelation of the weekly loads. The larger the value for this measure, the longer the periods of underloads or overloads, and the larger the difference between the average planned load and the actual load.

The second load variability performance measure is the autocorrelation of the weekly loads summed over all departments. The equation is:
\[ Y_4 = \frac{250}{\sum_{g=1}^{G} \sum_{t=1}^{250} (P_g - L_{g,t-1}) + (P_g - L_{g,t})} \] (6)

where

- \( P_g \) = the planned average load over the horizon for all machines in department \( g \).
- \( L_{g,t} \) = the actual load in week \( t \) for department \( g \).
- \( G \) = the number of departments.

The load is measured in hours of work per week.

For example, if the planned average load is set at 90% of capacity, and there are two machines in department \( g \), \( P_g \) would be 72 hours (80 x .9). This measure calculates the weekly difference in planned load and actual load, and computes the absolute sum of this difference for consecutive weekly periods. Consequently, long periods or "runs" of underloads or overloads will be penalized by this measure. Therefore, the objective of this measure is to have values as close to zero as possible so that long periods of large underloads and overloads are kept to a minimum.

**Average Standard Deviation of the Load Across the Shop – \( Y_5 \)**

The third load measuring device also utilizes the average standard deviation of the load, but is computed across the entire shop as a whole. The equation is:
\[ Y_5 = \left[ \frac{250}{\sum_{t=1}^{249} (L_t^o - L_t)^2} \right]^{1/2} \]  

(7)

where

- \( L = \) average load over the horizon for all machines in the shop.
- \( L_t = \) load in week \( t \) for all machines in the shop.

Comparisons between the measures \( Y_5 \) and the average standard deviation of the load summed over all departments \( Y_3 \) are valid because the same total number of machines is analyzed in each situation. If \( Y_3 \) had been divided by the number of departments in the shop, in order to avoid confounding with the number of departments, then \( Y_3 \) and \( Y_5 \) would have different scales and comparisons would not be accurate.

Once again the objective of this measure is to have values as close to zero as possible.

**Autocorrelation of the Weekly Loads Across the Shop - \( Y_6 \)**

The fourth load variability performance measure is the autocorrelation of the weekly loads across the shop. As with \( Y_3 \) and \( Y_5 \), comparisons can also be made between \( Y_4 \) and \( Y_6 \). The equation is:
\[ Y_6 = \sum_{t=1}^{250} \left( (P - L_{t-1}) + (P - L_t) \right) \]  

249

where

\( P \) = the planned average load over the horizon for all machines in the shop. For example, if the average load is set at 90\% of capacity and there are 20 machines in the shop, \( P \) would be 720 hours (800x.9).

\( L_t \) = the actual load in week \( t \) for all machines in the shop.

Once again the objective of this measure is to have values as close to zero as possible. Examples of all four load variability measures for the one department case are in Table 2.

3.4.2 Secondary Performance Measures

The MRPSIM simulator allows for the collection of a comprehensive set of performance measures. The measures discussed in this section are somewhat generalizable, and many have been used by other researchers. Other measures could be incorporated in future studies. These secondary performance measures can be used to interpret and help explain the results of this study. They provide more insight into the detailed operation of the shop, as well as offering some aid to the validation of the simulation, and will be employed if necessary to support the conclusions of this study.
Table 2

Example of Load Variability Measures Calculations

<table>
<thead>
<tr>
<th>Case 1 - Steady Load throughout horizon (in hours/wk)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Load</strong></td>
</tr>
<tr>
<td>Dept. 1</td>
</tr>
<tr>
<td>Dept. 2</td>
</tr>
</tbody>
</table>

Y₃=0.0   Y₄=0.0   Y₅=0.0   Y₆=0.0

<table>
<thead>
<tr>
<th>Case 2 - Periods of underloads and overloads</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Load</strong></td>
</tr>
<tr>
<td>Dept. 1</td>
</tr>
<tr>
<td>Dept. 2</td>
</tr>
</tbody>
</table>

Y₃=27.4   Y₄=30.0   Y₅=27.4   Y₆=20.0

<table>
<thead>
<tr>
<th>Case 3 - Alternating underloads and overloads</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Load</strong></td>
</tr>
<tr>
<td>Dept. 1</td>
</tr>
<tr>
<td>Dept. 2</td>
</tr>
</tbody>
</table>

Y₃=27.4   Y₄=0.0   Y₅=27.4   Y₆=0.0

<table>
<thead>
<tr>
<th>Case 4 - Random underloads and overloads</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Load</strong></td>
</tr>
<tr>
<td>Dept. 1</td>
</tr>
<tr>
<td>Dept. 2</td>
</tr>
</tbody>
</table>

Y₃=14.1   Y₄=16.0   Y₅=0.0   Y₆=0.0
These secondary performance measures are the mean, standard deviation, minimum, and maximum for the:

(a) flowtime per item, finished goods, intermediate goods and total inventory,

(b) work time per item, finished goods, intermediate goods, and total inventory,

(c) lateness per item, finished goods, intermediate goods, and total inventory,

(d) tardiness per item, finished goods, intermediate goods, and total inventory,

(e) release delay due to insufficient components per item, finished goods, intermediate goods, and total inventory,

(f) queue statistics by department; and the

(g) number of attempted order releases during the simulation,

(h) number of released orders during the simulation,

(i) number of orders released with reduced order quantities during the simulation,

(j) mean machine utilization by department, and

(k) mean setup time as a percentage of total available machine time by department.
### 3.5 Research Design of the Sample Experiment

As previously defined, the factors and the number of levels for each factor are as follows:

<table>
<thead>
<tr>
<th>Factor</th>
<th>Number of Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of levels in BOM</td>
<td>2</td>
</tr>
<tr>
<td>Degree of Work Center Specialization</td>
<td>2</td>
</tr>
<tr>
<td>Magnitude of the lot size</td>
<td>2</td>
</tr>
<tr>
<td>Priority rule</td>
<td>2</td>
</tr>
<tr>
<td>Gateway department</td>
<td>2</td>
</tr>
<tr>
<td>Average shop load</td>
<td>2</td>
</tr>
<tr>
<td>End item demand variability</td>
<td>2</td>
</tr>
</tbody>
</table>

A full factorial analysis would involve $128 \ (2^7)$ cells per replication. Due to the stochastic nature of several of the parameters in the BOM generator, and in order to make the study more generalizable, replications of each cell in the design are desirable. A replication involves generating a new BOM that has the appropriate level of each factor required for a cell in the design. If a full factorial analysis of all 7 factors is performed, at least $256 \ (2^7 \times 2 \text{replications})$ simulation runs are needed. This large number of runs is considered to be too prohibitive by the author. Therefore, due to the exploratory nature and the large number of factors in this research, a fractional factorial design is utilized in a sample experiment to identify which of the factors have the most significant
effects upon the dependent variables. The factor(s) that have no apparent significant effect on the performance measures at the 95% confidence level are dropped from further consideration by either fixing their level or randomizing their values. By making these test runs the error variance and power of the analysis are determined, so that the number of replications of the complete factorial design could be computed. In order to do the power analysis, however, multiple replications of the research design are necessary.

The sample experiment involved a saturated, resolution III, one-sixteenth fractional factorial design, or 8 \((2^{7-4})\) cells per replication. The generators and cells are in Appendix D, as well as the aliases of each main effect. Through this design seven main effects can be estimated in only eight simulation runs. No main effects are confounded with other main effects, but are confounded with lower level interactions. Also, only the treatment means for each main effect can be computed.

3.5.1 Research Hypotheses

In order to perform the power analysis and hypothesis testing, alternative hypotheses concerning the differences between the means of each level for each research factor must be specified. A total of 49 hypotheses are tested in the sample experiment, but due to repetitiveness an abbre-
viated description for the seven research factors is given. The following are hypotheses for each of the seven research factors for the seven performance measures.

**H₀₁:** the number of levels in the BOM has no effect upon the seven performance measures.

**H₁:** the values of the seven performance measures will be greater for 8 levels in the BOM than for 4 levels.

**H₀₂:** the degree of work center specialization has no effect upon the seven performance measures.

**H₁₂:** the values of the seven performance measures will be greater for more specialized work centers than for less specialized work centers.

**H₀₃:** the magnitude of the lot size has no effect upon the seven performance measures.

**H₃:** the values of the seven performance measures will be greater for the large lot sizes than for the small lot sizes.

**H₀₄:** the choice of priority rule has no effect upon the seven performance measures.

**H₄:** the values of the seven performance measures will be greater for the Due Date rule than for the Shortest Processing Time rule.

**H₀₅:** the degree of end item demand variability has no effect upon the seven performance measures.

**H₅:** the values of the seven performance measures will be
greater for high end item demand variability than for no end item demand variability.

Ho6: the magnitude of the average load has no effect upon the seven performance measures.

Ha6: the values of the system performance measures will be greater, while the load variability measures will be smaller, for a higher average load than for a lower average load.

Ho7: the use of gateway departments has no effect upon the seven performance measures.

Ha7: the values of the seven performance measures will be greater for shops with gateways than for shops without gateways.

Each of these hypotheses therefore has seven implied hypotheses, one for each of the performance measures, for a total of 49 hypotheses.

The above hypotheses are sufficient for the purpose of the sample experiment, which is basically to determine if any of the research factors could be dropped from further consideration in this study due to insufficient evidence of effects strong enough to be identified by this research methodology.

3.5.2 Data Analysis Methodology for Sample Experiment

In order to test the 49 alternative hypotheses, and due to the factorial nature of the research design, the
use of analysis of variance techniques is appropriate, and since a uniform sample size per cell is utilized these techniques should be valid even if their underlying assumptions are violated. The Statistical Analysis System's (SAS) (65) General Linear Model (GLM) is used to perform all of the calculations. Due to the saturated design only main effects are tested in the analysis. However, each of the main effects is confounded with two-way or higher interactions. For each of the seven main effects on each of the seven performance measures an F-ratio is calculated to determine if that effect has a significant effect on that performance measure, and consequently, to determine if any of the alternative hypotheses are valid.

In order to determine the probability that the study could have statistically significant results, a power analysis was performed on each of the main effects for each of the decision criteria. At least two replications per cell in the sample design is needed for the power analysis due to the saturated design, and, as more replications are performed, the power of the test will increase. For this sample experiment a power of .80 or above was considered necessary, and replications were performed until almost all of the main effects had reached this value, or until the power did not change appreciably with the addition of another replication.
Once the above analysis was completed, the number of replications needed for a full factorial design analysis to have a power of .90 was determined. Both sets of calculations were computed with significance value of .05 using the power analysis techniques of Cohen [20]. The calculations appear in Appendix F.

If a research factor has a very low F-ratio on most of the decision criteria, it was dropped from further consideration in the full factorial experimental design. This was due to computer cost considerations, since a full factorial experiment would involve at least 128 \(2^7\) simulation runs, plus replications. Therefore, depending upon the results of the analysis of variance and power analysis, a tradeoff between either reducing the number of factors, or reducing the number of replications was necessary.

The final analysis involves comparing the \(R^2\) for each performance measure model having 7 factors to the \(R^2\) for each analogous performance measure model having fewer than 7 factors. This comparison can only be made if any of the research factors are dropped from further consideration. A new SAS GLM computer run is made using the sample research data, with only the research factors that are to be included in the main experiment. The \(R^2\)'s
for this run are then compared to the previous $R^2$'s. This comparison must be performed because if a research factor is dropped from the experiment, then all of the interaction terms involving that factor are also dropped. Since the main effects are confounded with various interaction terms in the sample experiment, and some of these interactions are dropped, then the significance of the main effect may be decreased. If the $R^2$ does not change when a factor has been dropped due to lower F-ratio values, then the interaction effects involving that factor also are not very significant. If the $R^2$ did not change significantly, then the decision to no longer consider those factors which have not been included in the full factorial study would be strengthened. Any factor that is dropped from further analysis in this research may not necessarily have an insignificant effect upon the decision criteria in another experiment but appeared to be of little significance in this research setting based on the statistical calculations that were performed.

3.6 Results of Sample Experiment

The previous section has established the research methodology for the sample experiment. In this section the results of the sample experiment are analyzed, which include: testing the hypotheses presented in Section 3.5.1,
conducting a power analysis for each of the main effects on each decision criteria, determining the sample size for the full factorial experiment, determining if any factors can be deleted from the full factorial experiment, and comparing the $R^2$ of the 7 factor model to the $R^2$ of the reduced model to test the effects of dropping factors from the main experiment.

Appendices E and F present the data that are the basis for discussion in this section. Appendix E presents the original results of all simulation runs for the seven primary performance measures. Appendix F presents the calculations of the power of the sample experiment and sample size required for the full factorial experiment. Tables 3 through 7 represent a summary of the analysis of variance calculations performed by the SAS program and the power analysis calculations. As with the appendices, these tables will be referenced throughout the rest of this chapter.

A brief description of each table follows. Table 3 summarizes the percentage change in the observed power between two replications and three replications of the fractional design in order to determine when enough replications had been performed. Table 4 summarizes the $F$-ratio calculated in the analysis of variance for each
Table 3

% Change in Power Between 2 and 3 Replications Per Cell
For the Sample Experiment

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>LEVEL</th>
<th>ITEMS</th>
<th>LOT</th>
<th>RULE</th>
<th>END ITEM</th>
<th>LOAD</th>
<th>GATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>.01</td>
<td>.02</td>
<td>.11</td>
<td>.12</td>
<td>.00</td>
<td>.50</td>
<td>.01</td>
</tr>
<tr>
<td>Y2</td>
<td>.00</td>
<td>.01</td>
<td>.00</td>
<td>.07</td>
<td>.00</td>
<td>.05</td>
<td>.01</td>
</tr>
<tr>
<td>Y3</td>
<td>.01</td>
<td>.03</td>
<td>.50</td>
<td>.07</td>
<td>.02</td>
<td>.07</td>
<td>.02</td>
</tr>
<tr>
<td>Y4</td>
<td>.02</td>
<td>.02</td>
<td>.25</td>
<td>.12</td>
<td>.01</td>
<td>.06</td>
<td>.02</td>
</tr>
<tr>
<td>Y5</td>
<td>.01</td>
<td>.10</td>
<td>.13</td>
<td>.14</td>
<td>.01</td>
<td>.12</td>
<td>.05</td>
</tr>
<tr>
<td>Y6</td>
<td>.01</td>
<td>.01</td>
<td>.33</td>
<td>.07</td>
<td>.00</td>
<td>.07</td>
<td>.02</td>
</tr>
<tr>
<td>Y7</td>
<td>.00</td>
<td>.33</td>
<td>.17</td>
<td>.00</td>
<td>.01</td>
<td>.36</td>
<td>.11</td>
</tr>
</tbody>
</table>
### Table 4

F-Ratio Values
For the Sample Experiment

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>LEVEL</th>
<th>ITEMS</th>
<th>LOT</th>
<th>RULE</th>
<th>END ITEM</th>
<th>LOAD</th>
<th>GATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>.60</td>
<td>9.26**</td>
<td>0.32</td>
<td>0.27</td>
<td>22.51**</td>
<td>.08</td>
<td>6.64*</td>
</tr>
<tr>
<td>Y2</td>
<td>27.20**</td>
<td>11.69**</td>
<td>91.91**</td>
<td>.71</td>
<td>164.58**</td>
<td>2.34</td>
<td>10.65**</td>
</tr>
<tr>
<td>Y3</td>
<td>13.84**</td>
<td>7.59*</td>
<td>.01</td>
<td>.75</td>
<td>11.43**</td>
<td>.78</td>
<td>4.58*</td>
</tr>
<tr>
<td>Y4</td>
<td>11.59**</td>
<td>6.92*</td>
<td>.03</td>
<td>.97</td>
<td>14.08**</td>
<td>.82</td>
<td>4.17</td>
</tr>
<tr>
<td>Y5</td>
<td>12.56**</td>
<td>.50</td>
<td>.75</td>
<td>.15</td>
<td>11.89**</td>
<td>.27</td>
<td>1.23</td>
</tr>
<tr>
<td>Y6</td>
<td>13.00**</td>
<td>5.10*</td>
<td>.02</td>
<td>.66</td>
<td>15.83**</td>
<td>.75</td>
<td>3.59</td>
</tr>
<tr>
<td>Y7</td>
<td>36.47**</td>
<td>.25</td>
<td>1.17</td>
<td>.00</td>
<td>7.74*</td>
<td>.47</td>
<td>2.56</td>
</tr>
</tbody>
</table>

$df = 1$

$\text{df}_{\text{error}} = 16$

$F_{.05} = 4.49*$

$F_{.01} = 8.53**$
Table 5
Means of the Main Effects for the Sample Experiment

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>LEVEL</th>
<th>ITEMS</th>
<th>LOT</th>
<th>RULE</th>
<th>END ITEM</th>
<th>LOAD</th>
<th>GATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>L</td>
<td>1009</td>
<td>1872</td>
<td>1313</td>
<td>1067</td>
<td>114</td>
<td>1247</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>1360</td>
<td>498**</td>
<td>1056</td>
<td>1303</td>
<td>2256**</td>
<td>1122</td>
</tr>
<tr>
<td>Y2</td>
<td>L</td>
<td>346</td>
<td>330</td>
<td>212</td>
<td>306</td>
<td>183</td>
<td>285</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>252**</td>
<td>268**</td>
<td>385**</td>
<td>291</td>
<td>414**</td>
<td>313</td>
</tr>
<tr>
<td>Y3</td>
<td>L</td>
<td>254</td>
<td>476</td>
<td>384</td>
<td>352</td>
<td>265</td>
<td>412</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>509**</td>
<td>287*</td>
<td>379</td>
<td>411</td>
<td>498**</td>
<td>351</td>
</tr>
<tr>
<td>Y4</td>
<td>L</td>
<td>635</td>
<td>1214</td>
<td>979</td>
<td>867</td>
<td>602</td>
<td>1049</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>1289**</td>
<td>709*</td>
<td>945</td>
<td>1057</td>
<td>1322**</td>
<td>875</td>
</tr>
<tr>
<td>Y5</td>
<td>L</td>
<td>98</td>
<td>177</td>
<td>180</td>
<td>156</td>
<td>100</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>229**</td>
<td>150</td>
<td>148</td>
<td>171</td>
<td>227**</td>
<td>154</td>
</tr>
<tr>
<td>Y6</td>
<td>L</td>
<td>486</td>
<td>887</td>
<td>742</td>
<td>677</td>
<td>460</td>
<td>791</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>979**</td>
<td>578*</td>
<td>723</td>
<td>788</td>
<td>1004**</td>
<td>673</td>
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<tr>
<td>Y7</td>
<td>L</td>
<td>9764</td>
<td>18278</td>
<td>16222</td>
<td>17723</td>
<td>14007</td>
<td>18529</td>
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<tr>
<td></td>
<td>H</td>
<td>25498**</td>
<td>16985</td>
<td>19040</td>
<td>17540</td>
<td>21256*</td>
<td>16733</td>
</tr>
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</table>

L = Mean of Factor at Low Level
H = Mean of Factor at High Level
### Table 6

**Power Analysis For The Sample Experiment**

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>LEVEL</th>
<th>ITEMS</th>
<th>LOT</th>
<th>RULE</th>
<th>END ITEM</th>
<th>LOAD</th>
<th>GATE</th>
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</thead>
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<tr>
<td>Y1</td>
<td>.13</td>
<td>.92</td>
<td>.10</td>
<td>.09</td>
<td>.99</td>
<td>.06</td>
<td>.06</td>
</tr>
<tr>
<td>Y2</td>
<td>.99</td>
<td>.97</td>
<td>.99</td>
<td>.15</td>
<td>.99</td>
<td>.40</td>
<td>.95</td>
</tr>
<tr>
<td>Y3</td>
<td>.98</td>
<td>.85</td>
<td>.03</td>
<td>.16</td>
<td>.96</td>
<td>.17</td>
<td>.68</td>
</tr>
<tr>
<td>Y4</td>
<td>.96</td>
<td>.84</td>
<td>.05</td>
<td>.19</td>
<td>.98</td>
<td>.17</td>
<td>.64</td>
</tr>
<tr>
<td>Y5</td>
<td>.98</td>
<td>.11</td>
<td>.17</td>
<td>.08</td>
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<td>.24</td>
</tr>
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<td>Y6</td>
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<td>.04</td>
<td>.15</td>
<td>.99</td>
<td>.17</td>
<td>.58</td>
</tr>
<tr>
<td>Y7</td>
<td>.99</td>
<td>.08</td>
<td>.21</td>
<td>.01</td>
<td>.87</td>
<td>.11</td>
<td>.40</td>
</tr>
</tbody>
</table>

\[ \alpha = .05 \]
Table 7  
Sample Size Per Cell  
Needed For The Main Experiment

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>LEVEL</th>
<th>ITEMS</th>
<th>LOT</th>
<th>RULE</th>
<th>END ITEM</th>
<th>LOAD</th>
<th>GATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
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<td>25</td>
<td>29</td>
<td>1</td>
<td>112</td>
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<td>1</td>
<td>1</td>
<td>12</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Y3</td>
<td>1</td>
<td>1</td>
<td>188</td>
<td>11</td>
<td>1</td>
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<td>2</td>
</tr>
<tr>
<td>Y4</td>
<td>1</td>
<td>1</td>
<td>144</td>
<td>8</td>
<td>1</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Y5</td>
<td>1</td>
<td>18</td>
<td>11</td>
<td>70</td>
<td>1</td>
<td>29</td>
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<td>1</td>
<td>2</td>
<td>157</td>
<td>12</td>
<td>1</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Y7</td>
<td>1</td>
<td>33</td>
<td>7</td>
<td>188</td>
<td>1</td>
<td>19</td>
<td>3</td>
</tr>
</tbody>
</table>

df\_num = 1  
df\_denom = 16  
\(\alpha\) = .05  
Power = .90
factor and each primary performance measure. An (*) denotes that the effect is significant at the .05 level of significance, and a (**) denotes that the effect is significant at the .01 level of significance. This notation is used throughout Tables 4, 5, 6, and 7. Table 5 summarizes the calculated means for each level of the seven factors for each of the seven performance measures.

Table 6 summarizes the power analysis performed on all of the effects in the three replication case. The higher the observed power, the greater the probability of statistically significant results if Ho is false.

Table 7 displays the sample size per cell in the full factorial experiment required to achieve a power of the test of .90 with an alpha value of .05 for each of the research factors and performance measures. The lowest value in any column of each research factor would be the minimum sample size per cell. Table 8 summarizes the % difference in R² for each performance measure's predictive model having 7 factors and 5 factors, respectively. For the 5 factor models, the priority rule and average load factors have been dropped.

3.6.1 Number of Replications Needed in the Test Experiment

The number of replications per cell of the test experiment is important in determining the statistical significance of the main effects and for performing the power
analysis. The larger the number of replications, the greater the power of the test will be, provided that a relationship does exist between the performance measures and research factors. Consequently, the greater the number of replications, the greater the likelihood of identifying significant relationships and verifying hypotheses. Ideally an infinite number of replications is desirable in order to sample the entire research population. However, due to financial and temporal limitations, as small of a sample size as is possible, yet still achieve adequate power, was required.

In analyzing the data in Table 3, the percentage change in power between 2 and 3 replications is very small, except where the power is so low that any small increase in size causes a large percentage change, as happened for the Y7-Items, Y3-Lot, Y4-Lot, Y7-Lot, Y7-Rule, Y1-Load, and Y7-Load. Consequently, there was no need to make more than 3 replications per cell for the sample experiment, since the power was not significantly improved when the third replication was made.

3.6.2 Testing of Sample Research Hypotheses

The following sections describe the results in Tables 4, 5, and 6 in relation to the sample research hypotheses in Section 3.5.1. The analysis involves the significance of the effect based upon the ANOVA F-ratio and power analy-
sis, analysis of means for each level of the research factor or on each performance measure, and testing of the hypotheses. 

Average Cumulative End Item Backorders (Y1) Performance

An analysis of the backorder performance in Tables 4, 5, and 6 reveals that only 3 of the 7 factors have significant main effects. End item demand variability has the most significant effect, followed by the degree of work center specialization, and gateway. In terms of the power analysis, these same three factors are significant, and the experiment was not powerful enough to detect differences for the other factors. An analysis of the means in Table 5 for each level of each factor shows that even though 4 of the factors are not statistically significant, there still may be some effect. For example, Figure 2 shows the means for both levels of all 7 of the factors with regard to cumulative end item backorders. The dotted lines on Figure 2-8 represent significance levels with \( \alpha = .05 \) for each of the performance measures. Any mean outside of these lines is significant above the .05 level.

In terms of alternative hypotheses 1-7 concerning this performance measure, 5 of the factors exhibited the behavior hypothesized, although the number of levels and priority rule factors are not statistically significant. However, for the magnitude of the lot size and the average load, the effects are the opposite of their alternative
Symbols for Figures 2-8
1 - # of levels in BOM
2 - w. c. specialization
3 - lot size
4 - priority rule
5 - end item demand variability
6 - average load
7 - gateway

Figure 2
Means of the Main Effects for the Average End Item Backorders in the Sample Study

Figure 3
Means of the Main Effects for the Average Inventory Units per Item for the Sample Study
hypotheses, though neither are statistically significant. Consequently \( Ho2 \), \( Ho5 \), and \( Ho7 \) can be rejected in favor of their alternative hypotheses for this performance measure.

**Average Inventory Units per Average Item (Y2) Performance**

An analysis of the average inventory units per average item performance in Tables 4, 5, and 6 reveals that 5 of the research factors had highly significant effects. Only the priority rule and average load are insignificant so that \( Ho4 \) and \( Ho6 \) can not be rejected for this performance measure. End item demand variability, magnitude of the lot size, and number of levels in the BOM are the most significant factors. Figure 3 displays a graph of the means for each of level of the factors.

In terms of the means in Table 5 the number of levels in the BOM and the priority rule had effects which are the opposite of their alternative hypotheses.

**Average Standard Deviation of the Load Summed over all Departments (Y3) Performance**

An analysis of the average standard deviations of the load summed over all departments in Tables 4, 5, and 6 reveals that end item demand variability and the number of levels in the BOM are the two most significant factors, while the degree of work center specialization and gateway also are significant. All of the effects are in agreement with the alternative hypotheses, as shown in Figure 4.
LEVEL OF THE RESEARCH FACTOR

Figure 4
Means of the Main Effects for the Average Standard Deviation of the Load Summed over all Departments for the Sample Study

LEVEL OF THE RESEARCH FACTOR

Figure 5
Means of the Main Effects for the Autocorrelation of the Weekly Load Summed over all Departments in the Sample Study
Consequently, $H_{01}, H_{02}, H_{05},$ and $H_{07}$ can be rejected in favor of the alternative hypotheses for this performance measure.

**Autocorrelation of the Weekly Loads Summed over all Departments ($Y_4$) Performance**

An analysis of this decision criterion's performance in Tables 4, 5, and 6 reveals that end item demand variability, the number of levels in the BOM, and the degree of work center specialization are all significant. As can be seen from Figure 5, only the priority rule does not agree with the alternative hypothesis. However, the means of both levels are very close in value, and the factor is not significant. Therefore, $H_{01}, H_{02},$ and $H_{05}$ can be rejected in favor of the alternative hypotheses for this performance measure.

**Average Standard Deviation of the Load Across the Shop ($Y_5$) Performance**

An analysis of this decision criterion's performance in Tables 4, 5, and 6 reveals that the number of levels in the BOM and the end item demand variability are the only significant effects. Also, the magnitude of the lot size has an effect opposite to the alternative hypothesis, but is not significant. $H_{01}$ and $H_{05}$ can be rejected in favor of the alternative hypotheses for this performance measure. Figure 6 displays the plots of the means.
Figure 6

Means of the Main Effects for the Average Standard Deviation of the Load Across the Shop in the Sample Study

Figure 7

Means of the Main Effects for the Autocorrelation of the Weekly Loads Across the Shop in the Sample Study
Autocorrelation of the Weekly Loads Across the Shop

(Y6) Performance

An analysis of this decision criterion's performance in Tables 4, 5, and 6 reveals that the end item demand variability, the number of levels in the BOM, and the degree of work center specialization are the most significant effects. The magnitude of the lot size is the only factor whose effect does not agree with the alternative hypothesis, as seen in Figure 7, but it is not significant. H01, H02, and H05 can be rejected in favor of the alternative hypotheses for this performance measure.

All four of the load variability measures had similar results, especially with respect to agreement of the effects to the alternative hypotheses.

Average Inventory Units (Y7) Performance

An analysis of the average inventory units performance in Tables 4, 5, and 6 reveals that only two of the research factors, number of levels in the BOM and end item demand variability, had significant effects. Consequently, H02, H03, H04, H06, and H07 can not be rejected for the performance measure. Figure 8 displays a graph of the means for each level of the factors.

In terms of the means in Table 5 the priority rule and average load factors have effects which are the op-
Figure 9

Means of the Main Effects for the Average Inventory Units
posite of their alternative hypotheses. The number of levels in the BOM's effect upon this performance measure (Y7) is the opposite of its effect upon the average inventory units per average item (Y2). This is due to the fact that Y7 is confounded with the number of levels in the BOM, as explained in Section 3.4.1.

3.6.3. **Determination of Sample Size for Full Factorial Experiment**

Table 7 displays the number of replications per cell required for a full factorial experimental design based upon the power calculations in Appendix F. A value of 1 appears in each column of every factor except the priority rule and the average load. Consequently, every factor, except the two just noted, could have a power of .90 for the statistical tests performed on a full factorial design with only 1 replication per cell for at least 1 performance measure.

3.6.4. **Factors to Include in Full Factorial Experiment**

As was previously mentioned a full factorial analysis of all 7 factors (128 runs) is not feasible due to budget limitations. By analyzing Tables 4, 5, 6 and 7 three possible full factorial designs are apparent. Only the number of levels in the BOM, the degree of work center specialization, end item demand variability, and gateway appear to be statistically significant on almost all
seven primary performance measures. Since at least 1 replication per cell is required to attain a power of .90, a full factorial design would involve 16 cells, or 16 simulation runs. Since resources are available for 64 runs, one alternative design would involve 6 factors with 1 replication per cell to achieve 64 runs. This alternative was not used in this research due to the arbitrariness of deleting either the priority rule or the average load from the design, since both have the same statistical significances on all seven of the decision criteria. Another alternative design involved using only the 4 most significant factors and using three replications per cell. By using this design, the study would not be as broad as originally intended. Consequently, the third alternative design was chosen involving the four most significant factors, plus the magnitude of the lot size factor, with two replications per cell. The magnitude of the lot size was included for two reasons: a) Table 7 shows that for average inventory units per item a sample size of 1 is needed; b) the factor was felt to be important from an empirical standpoint. Two replications per cell aided in increasing the generalizability of the study, as well as the statistical tests, due to increasing the degrees of freedom for the F-ratios and providing an error term.
In summary, the full factorial experimental design will involve 5 factors with two replications per cell, or 64 simulation runs. The factors are: the number of levels in the BOM, the degree of work center specialization, the magnitude of the lot size, end item demand variability, and gateways.

3.6.5 Comparison of $R^2$'s

Using the sample experiments' data, an analysis of variance was performed on all seven of the decision criteria using a model with the 5 factors which are to be part of the full factorial experiment. This was done as a check to make sure that by deleting the priority rule and average load factors, the significance and condition of the model to the decision criteria did not greatly change. By deleting the two factors, the $R^2$ would be expected to decrease due to a poorer "fit" of the regression model to the data. However, the degrees of freedom for the mean square error will increase, and if the two factors and all of their interactions did not account for much of the "explainable" variance due to their insignificance, the significance of the other factors' effects should increase. As can be seen from Table 8, the $R^2$ did not change much between the 7 and 5 factors case, so that dropping the average load and the priority rule factors does not appear to have a negative impact upon the results and findings of this chapter.
<table>
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<tr>
<th>DEPENDENT VARIABLE</th>
<th>7 Factors</th>
<th>5 Factors</th>
<th>Diff.</th>
<th>% Change</th>
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<td>Y1</td>
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<td>.0063</td>
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<tr>
<td>Y2</td>
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<td>.0094</td>
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<td>.0277</td>
<td>3.9</td>
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<tr>
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<td>.6214</td>
<td>.0095</td>
<td>1.5</td>
</tr>
<tr>
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<td>.6832</td>
<td>.0256</td>
<td>3.6</td>
</tr>
<tr>
<td>Y7</td>
<td>.7525</td>
<td>.7451</td>
<td>.0074</td>
<td>1.0</td>
</tr>
</tbody>
</table>
The average load and priority rule factors have been hypothesized to have an effect upon system performance and load variability. However, this research could find no such statistically significant relationships. However, for the priority rule factor, SPT did perform better than DD on the backorder (22% lower) and load variability measures (about 16% lower), which agrees with Ha4. For the average load factor, a 90% load level had better performance (about 16% lower) for the load variability measures, which agrees with Ha5, but also better performance (about 11% lower) for backorders and average inventory units, which does not agree with Ha6. While not being statistically significant at the .05 alpha level, these results show that the factors may still have some effect upon system performance and load variability. There are four possible reasons why no statistically significant results were obtained, which are: (1) no relationship exists in actuality; (2) the sample size is too small to discern the relationship; (3) the fractional factorial design, due to the large number of confounded interactions, may not be powerful enough to discern an effect; and (4) the simulation may not be complex and realistic enough to display a difference. Also, for the average load factor, two other explanations are possible, which are: (1) the levels chosen (85% and 90%) are not far enough apart to
differentiate the relationships; and (2) the relationships between the performance measures and the average load is dish shaped, so that within a certain range for the load, the performance measures are unaffected, but at the extremes performance decreases. Therefore, further study of these two factors is necessary before $H_04$ and $H_06$ can be rejected.

3.7 Summary

This chapter discussed the seven research factors and seven performance measures utilized in this study. The general research methodology and the fractional factorial experimental design of the sample experiment were also discussed. A brief description of the research vehicle, MRPSIM, and its parameter settings was included. The chapter concludes with the results and analysis of the sample experiment. Five of the research factors, the number of levels in the BOM, the degree of work center specialization, the magnitude of the lot size, the degree of end item demand variability, and gateway departments, are included in the main experimental design, while the other two, priority rules and average load, will not be further analyzed in this study. Chapter IV discusses the main experiment which involves a full factorial design and two replications per cell.
CHAPTER IV

METHODOLOGY AND ANALYSIS OF MAIN EXPERIMENT

In this chapter the design and analysis of the main experiment are discussed. The primary performance measures to be analyzed are: average cumulative end item backorders, average inventory units per average item, average inventory units, average standard deviation of the load across the shop, average standard deviation of the load summed over all departments, autocorrelation of the weekly loads across the shop, and autocorrelation of the weekly loads summed over all departments. For each of these performance criteria the appropriate research questions, which are presented in Section 4.1.1, are addressed. Once all of the research questions are addressed, the results will be summarized at the end of this chapter.

4.1 Research Design of the Main Experiment

In Section 3.6 the sample experiment was analyzed and discussed; consequently five of the research factors were chosen to be included in the main experiment. The five factors, with two levels each, are: number of levels in the BOM, degree of work center specialization, magnitude of the lot size, end item demand variability, and
gateway departments. The average load on the system is fixed at 90 percent of capacity since most of the previous job shop literature utilized this level. The Due Date rule is used for setting priorities of the orders in queue since it is popular among practitioners. In order to analyze all of the main effects and interactions of these factors, a full factorial design is used, involving 32 \(2^5\) cells per replication. Based upon the results of the power analysis and the limitation upon the total number of simulation runs, two replications per cell are made, for a total of 64 simulation runs. A total of 64 bills of materials are generated, one for each observation in each cell of the design, so that a large sample of product structures is attained.

A replication of a cell involves specifying the appropriate level of each factor and generating a new BOM meeting those requirements. Each replication involves the same distributions for all of the parameters utilized in the BOM generator, but with a new random number seed to guarantee a random sample from the specified population.

4.1.1 Specific Research Hypotheses

To organize the presentation of the simulation results and to focus attention on issues of interest a series of null and alternative hypotheses are posed below. Most of these hypotheses are directed to a single criterion, with
each being addressed later in this chapter. The following are the hypotheses posed in this research.

**H01**: Each of the five research factors and their interactions have no overall effect upon the 7 performance measures,

**H02**: Each of the 5 research factors and their interactions have no effect upon average cumulative end item backorders.

**H03**: Each of the 5 research factors and their interactions have no effect upon the average inventory units per average item.

**H04**: Each of the 5 research factors and their interactions have no effect upon the average inventory units.

**H05**: Each of the 5 research factors and their interactions have no effect upon the average standard deviation.
of the load summed over all departments.

**Hₐ₅**: Each of the 5 research factors and their interactions have an effect upon the average standard deviation of the load summed over all departments.

**H₀₆**: Each of the 5 research factors and their interactions have no effect upon the autocorrelation of the weekly loads summed over all departments.

**Hₐ₆**: Each of the 5 research factors and their interactions have an effect upon the autocorrelation of the weekly loads summed over all departments.

**H₀₇**: Each of the 5 research factors and their interactions have no effect upon the average standard deviation of the load across the shop.

**Hₐ₇**: Each of the 5 research factors and their interactions have an effect upon the average standard deviation of the load across the shop.

**H₀₈**: Each of the 5 research factors and their interactions have no effect upon the autocorrelation of the weekly loads across the shop.

**Hₐ₈**: Each of the 5 research factors and their interactions have an effect upon the autocorrelation of the weekly loads across the shop.

**H₀₉**: Load variability has no effect upon system performance.

**Hₐ₉**: Load variability has an effect upon system perfor-
mance.

Ho10: Load variability simultaneously measured across the shop is as good of a predictor of system performance as are load variabilities measured at each individual department.

Ha10: Load variability simultaneously measured across the shop is a poorer predictor of system performance than load variabilities measured at each individual department.

4.1.2 Methods for Analysis of Data

Hypotheses 1-8 posed in the previous section are addressed and conclusions made based on four general data analysis approaches, three of which were previously discussed in Section 3.5. These are:

1) multivariate analysis of variance (MANOVA)

2) analysis of variance involving F-tests to determine the statistical significance of the 5 main effects and 26 interaction effects on each of the seven performance measures,

3) power analysis to calculate the probability of determining the statistical significance of each of the 5 main effects and 26 interaction effects on each of the seven performance measures, and

4) analysis of the means of each of the levels
for all the effects.

The first method, MANOVA, analyzes the effects that the five research factors and their interactions have upon a vector of all seven of the performance measures simultaneously and relates to Hypothesis 1. An F-ratio is computed, using SAS's GLM MANOVA subroutine, for each of the main effects and interaction effects' relationships to the dependent vector of the seven performance criteria in order to determine the statistical significance of the effects. If an effect is significant, then that variable has a strong effect upon the performance measure vector. If an effect is insignificant then univariate tests for that effect should not be performed. The last three methods basically involve analyzing the effects that the five research factors and their interactions have upon each of the seven performance measures, and relate to Hypotheses 2-8.

Hypotheses 9 and 10 are meant to examine relationships among the performance criteria, and conclusions made about these two hypotheses are based upon two general data analysis approaches. The first approach involves factorial discriminant analysis of the performance measures. The discriminant analysis is usually limited to the main effects of the factors, since interaction terms are very difficult to interpret. The discriminant analysis basically involves
determining which of the performance measures are most significantly affected by the research factor, or in other words, the discriminant analysis calculates the research factors' ability to discriminate with regard to the performance measures. The discriminant analysis computes a discriminant function for each effect, and the performance measures with the highest absolute discriminant value in this function are the measures that the factor uses most for discriminating between the groups.

The second analysis technique is correlation analysis, which was computed using SAS's CORR procedure. This procedure calculates the correlation coefficient's, $\rho$, between variables using Pearson's product-moment correlations and performs significance tests for $H_0: \rho = 0$. The correlation coefficient measures the relationship between any two variables, so that the higher the correlation coefficient, the stronger the relationship between the two variables. If the coefficient is positive, then the two variables change values in conjunction with each other; if the coefficient is negative, then as one of the variables increases in value, the other variable decreases in value. The correlation coefficient is between $-1$ and $+1$, with no correlation signified by zero.

Hypothesis 10 was analyzed using correlation analysis since the question involved only performance measures.
If there is a relationship between load variability and system performance, then the correlation coefficients between these measures should be significantly different from zero.

Hypothesis 9 was analyzed using factorial discriminant analysis and correlation analysis on the seven performance measures for each of the research factors that had a significant MANOVA effect. By comparing the discriminant functions values for each of the performance measures, a ranking of their relationship to the research factor shows which measures are discriminated best by that factor. So by comparing the rankings of the performance measures taken across the entire shop to the performance measures summed over all departments, as well as the correlations between the system performance measures and the load variability measures, the question can be answered.

4.2 Analysis of Results for Primary Performance Measures

Appendices G and H present the data that are the basis of discussion for the rest of this chapter. Appendix G presents the original results of all simulation runs in the main experiment for these seven primary performance measures. Appendix H presents the power analysis and factorial discriminant analysis calculations. The statistics are computed for each of the five main effects on
each of the seven primary performance measures.

Tables 9 through 14 represent the results of the analysis of variance for the main experimental data. Table 9, or the MANOVA results, lists the main effects' significances with respect to the multivariate analysis of variance. Tables 10 and 11 represent the results of the analysis of variance, multivariate analysis of variance, and analysis of the means for all the significant interaction effects in the experiment.

Tables 12, 13, and 14 represent the results of the analysis of variance, power of the test, and analysis of means for the main effects in the experiment. Table 12 also includes the components of variance in parentheses for each factor. This value represents the percentage of total variance explained by the effect of that factor.

Research hypotheses 1-8 posed in Section 4.1.1 shall now be addressed, as well as any other findings of interest. The 8 hypotheses represent sub-sections of this chapter in which each of the five research factors and their interactions are addressed. For ease of discussion, the names of the performance measures and research factors are abbreviated.

4.2.1 Multivariate Analysis of Variance

This section discusses the results of the multi-
<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Wilks' F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>LOT</td>
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<td>.0001</td>
</tr>
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<td>END ITEM</td>
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<td>.0001</td>
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<tr>
<td>GATEWAY</td>
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<td>.1197</td>
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$df_{num} = 7$

$df_{denom} = 26$
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<th>Y3</th>
<th>Y4</th>
<th>Y5</th>
<th>Y6</th>
<th>Y7</th>
<th>MANOVA</th>
</tr>
</thead>
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<tr>
<td>LEVEL*ITEM</td>
<td>1.05(0.6)</td>
<td>0.78(0.1)</td>
<td>1.19(0.6)</td>
<td>0.96(0.5)</td>
<td>0.20(0.2)</td>
<td>0.59(0.3)</td>
<td>1.44(0.3)</td>
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<td>LEVEL*LOT</td>
<td>4.46*(2.6)</td>
<td>4.48*(0.6)</td>
<td>1.67(0.8)</td>
<td>1.69(0.9)</td>
<td>2.62(2.3)</td>
<td>1.78(1.1)</td>
<td>0.08(0.2)</td>
</tr>
<tr>
<td>LEVEL*RED ITEM</td>
<td>0.49(0.3)</td>
<td>68.59**(9.6)</td>
<td>6.70*(1.4)</td>
<td>8.01**(4.1)</td>
<td>1.53(1.3)</td>
<td>6.94*(4.2)</td>
<td>5.40*(7.1)</td>
</tr>
<tr>
<td>TREATMENT</td>
<td>0.20(0.1)</td>
<td>0.22(0.0)</td>
<td>0.12(0.1)</td>
<td>0.07(0.0)</td>
<td>1.77(1.6)</td>
<td>0.14(0.1)</td>
<td>0.95(0.2)</td>
</tr>
<tr>
<td>TREATMENT*RED ITEM</td>
<td>5.21*(3.0)</td>
<td>0.69(0.1)</td>
<td>6.71*(1.4)</td>
<td>6.61*(3.0)</td>
<td>2.49(2.3)</td>
<td>4.72**(2.0)</td>
<td>14.62*** (3.0)</td>
</tr>
<tr>
<td>TREATMENT*ITEM</td>
<td>0.04**(4.7)</td>
<td>0.43(0.0)</td>
<td>6.72**(3.4)</td>
<td>7.28*(3.7)</td>
<td>7.87**(7.1)</td>
<td>7.03**(4.3)</td>
<td>3.05(0.6)</td>
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<td>LEVEL<em>ITEM</em>END ITEM</td>
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<td>0.22(0.0)</td>
<td>1.13(0.6)</td>
<td>1.12(0.6)</td>
<td>0.37(0.3)</td>
<td>0.81(0.5)</td>
<td>3.07(0.0)</td>
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</tbody>
</table>

( ) designates the percentage of total variance caused by this Factor for this performance measure.

* Significant at .05 level
** Significant at .01 level
*** Significant at .001 level
Table 11
Means for all Levels of
Significant Interactions

\[ \alpha = 0.05 \]

L = Low level
H = High level

<table>
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<tr>
<th>Independent variable</th>
<th>Y1</th>
<th>Y2</th>
<th>Y3</th>
<th>Y4</th>
<th>Y5</th>
<th>Y6</th>
<th>Y7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LEVEL * LOT</strong></td>
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<td>1293</td>
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<td>HL</td>
<td>1047</td>
<td>218</td>
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<td>HH</td>
<td>489</td>
<td>287</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td><strong>LEVEL * END ITEM</strong></td>
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<td></td>
</tr>
<tr>
<td>LL</td>
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<td>365</td>
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</tr>
<tr>
<td>HL</td>
<td>179</td>
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<td>672</td>
<td>508</td>
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<td>LH</td>
<td>558</td>
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<td>1665</td>
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<tr>
<td><strong>ITEM * END ITEM</strong></td>
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<td></td>
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</tr>
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<td>697</td>
<td>512</td>
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<td>1263</td>
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<td>958</td>
<td>771</td>
<td>20792</td>
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<td></td>
</tr>
<tr>
<td><strong>LOT * END ITEM</strong></td>
<td></td>
<td></td>
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<td>LL</td>
<td>103</td>
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<td>385</td>
<td>66</td>
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<td>110</td>
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<td>Y3</td>
<td>Y4</td>
<td>Y5</td>
<td>Y6</td>
<td>Y7</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------</td>
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<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Level</td>
<td>11.56** (6.7)</td>
<td>105.59** (14.8)</td>
<td>33.07** (16.7)</td>
<td>24.32** (12.5)</td>
<td>10.95** (9.5)</td>
<td>19.76** (12.1)</td>
<td>197.52** (41.1)</td>
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<tr>
<td>Items</td>
<td>23.41** (13.6)</td>
<td>20.19** (1.4)</td>
<td>31.06** (15.7)</td>
<td>27.23** (14.0)</td>
<td>2.96 (2.6)</td>
<td>16.54** (10.1)</td>
<td>23.11** (4.8)</td>
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<tr>
<td>Lot</td>
<td>0.64 (0.3)</td>
<td>58.92** (8.2)</td>
<td>2.71 (0.1)</td>
<td>2.32 (1.1)</td>
<td>1.70 (1.5)</td>
<td>1.14 (0.6)</td>
<td>20.02** (4.1)</td>
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<td>End Item</td>
<td>69.23** (40.3)</td>
<td>402.87** (56.5)</td>
<td>56.75** (28.7)</td>
<td>65.45** (33.7)</td>
<td>25.28** (22.9)</td>
<td>54.13** (33.1)</td>
<td>150.60** (31.3)</td>
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<td>Gateway</td>
<td>0.23 (0.1)</td>
<td>0.64 (0.0)</td>
<td>0.37 (0.1)</td>
<td>0.45 (0.2)</td>
<td>1.50 (1.3)</td>
<td>0.62 (0.3)</td>
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( ) designates the percentage of total variance caused by this factor for this performance measure.

\[
\text{df}_{\text{num}} = 1
\]
\[
\text{df}_{\text{denom}} = 32
\]
\[
F_{.05} = 4.15 \ *
\]
\[
F_{.01} = 7.51 \ **
\]
Table 13

Power of the Test for the Main Effects*

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<th>Independent Variable</th>
<th>Y1</th>
<th>Y2</th>
<th>Y3</th>
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<th>Y5</th>
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<td>.44</td>
<td>.32</td>
<td>.19</td>
<td>.99</td>
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<td>.05</td>
<td>.06</td>
<td>.26</td>
<td>.08</td>
<td>.29</td>
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</tbody>
</table>

* Testing the alternative hypothesis that there is a large difference in means between the levels of each factor.

\[ \alpha = .01 \]

\[ df_{num} = 1 \]

\[ df_{denom} = 32 \]
Table 14
Means for Each Level of Main Effects

<table>
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<th>Y2</th>
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<td>21392**</td>
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<td>707</td>
<td>136</td>
<td>567**</td>
<td>16448</td>
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<tr>
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</tr>
<tr>
<td>Low</td>
<td>1170</td>
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<td>350</td>
<td>875</td>
<td>180</td>
<td>685</td>
<td>16619**</td>
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<td>Low</td>
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<td>191**</td>
<td>255**</td>
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<td>1312</td>
<td>234</td>
<td>1017</td>
<td>25230</td>
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<td><strong>GATEWAY</strong></td>
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</tr>
<tr>
<td>Low</td>
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<tr>
<td>High</td>
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<td>322</td>
<td>386</td>
<td>975</td>
<td>179</td>
<td>758</td>
<td>19608</td>
</tr>
</tbody>
</table>

* Significant at .05 level
** Significant at .01 level
variate analysis of variance calculations, which were computed by the SAS GLM subroutine, in terms of Hypothesis 1. The model for the multivariate analysis of variance in this analysis involves all seven on the performance measures as a vector of dependent variables, with each of the 5 research factors and interactions as independent variables. The analysis determines if an effect is significant on all seven decision measures simultaneously. If the effect is statistically significant then the univariate F-ratios can be used to determine the performance measures that are most affected by the research effect. Any main effect that is significant implies a strong relationship between that effect and the performance measures. However, as was mentioned in Section 4.1.2, if interactions involving that main effect are also significant the importance of the main effect is somewhat diminished. A discussion of the results for the main effects and then the implications of the interaction effects completes this section.

Table 9 reveals the approximate F-ratios computed by using Wilks' criterion by the SAS GLM subroutine for each of the 5 main effects in relation to the vector of the seven performance measures. All of the factors, except gateway, are highly statistically significant, with end
item demand variability having the highest F-ratio. Therefore, when analyzing all seven performance measures concurrently, end item demand variability has the most significant effect, with the number of levels in the BOM, the degree of work center specialization, and the magnitude of the lot size having the next most significant effects, respectively. The use of a gateway department has no significant effect on any of the performance measures and will not be included in the univariate F-ratio discussions.

The far right hand column of Table 10 gives the results of the multivariate analysis of variance for the interaction effects. Seven of the 26 interactions are statistically significant, with the number of levels-end item demand variability interaction having the largest approximate F-ratio. However, for a set of K interactions, the probability of rejecting at least one null hypothesis when in fact it is true is equal to \(1-(1-\alpha)^K\). For this analysis the probability is \(1-(1-.05)^{26} = .736\), so that there is a fairly good probability that at least one of these 7 interactions is actually null. Four of the six interactions' implications are discussed in upcoming parts of Section 4.2, and the other two interactions will now be discussed.

The number of levels - work center specialization interaction and the work center specialization - lot size
interaction are both statistically significant for the multivariate analysis. However, neither had univariate statistical significance for any of the seven performance measures. The means in Appendix K for each level of these interactions reflect the relationship exhibited in Table 14 when each factor is taken individually.

In summary four main effects and seven interaction effects are significant for the multivariate analysis of variance. Gateway departments have no effect upon the dependent measures for the multivariate statistical analysis. In fact, it had no statistical significance for the univariate analyses, either. However, gateway departments are significant in the sample fractional factorial experiment for three of the dependent measures (see Table 4, page 91). There are two possible explanations for this conflict: (1) the sample size was unrepresentative or too small in the fractional factorial experiment; (2) the gateway main effect is confounded with 15 interaction terms in the sample experiment. Consequently, if any of these 15 interactions are significant, then the gateway main effect being analyzed will appear significant, also. For the main experiment, the gateway factor's effect is estimated individually (no confounding with interaction terms), so that only the gateway factor's significance is being tested. Apparently this second explanation
describes what has occurred here. Appendix D shows that the gateway main effect is confounded with the work center specialization - demand variability interaction in the sample experiment. Table 10 shows that this interaction is the second most significant interaction in the MANOVA analysis. Therefore, the significance of the gateway factor in the sample experiment may not be valid, and the main experiment's results should be more accurate.

4.2.2 **Average Cumulative End Item Backorders - Y1**

This performance measure is a representative of the general performance of the manufacturing system, and relates to a general objective of management to maintain a level of good customer service. A performance objective would be to minimize the value for this measure in order to provide satisfactory customer service.

The following is a **discussion** for each of the 5 research factors, pertaining to Hypotheses 2 in Section 4.1.1.

An analysis of the F-ratios and powers presented in Tables 12 and 13 reveals that three factors, end item, items, and level have significant effects at the .01 level upon backorders, with components of variance of 40.3%, 13.6% and 6.7%, respectively. Lot and gateway had no significant effect upon backorders in this research.

An analysis of the means in Table 14 for the levels of the factors proves informative. Four levels in the BOM
causes almost twice as many backorders as eight levels in the BOM does. This is contrary to the alternative hypothesis proposed in Section 3.3 as well as the sample results. Apparently what occurs in this situation is that the larger number of levels buffer variations in component supply to the end items by having more stocking points for work-in-process inventory, and give more planning lead time to the system as well, since in this study, as the number of levels increases so does the cumulative production lead time and the total number of items. The increased lead time and number of items would increase the likelihood of the system being able to react to variations in demand and availability of parts and increase the total inventory in the system, possibly helping performance. If orders were arriving in small quantities throughout the system, smoothing would not be difficult, so the effect of having more levels would not be as important to someone designing a BOM. However, if orders were arriving in large quantities, which would be more difficult to smooth, then having more levels would be an aid to smoothing out production problems. The level-lot interaction in Table 11 and Figure 10 supports this hypothesis since 8 levels in the BOM improves backorders for both small and large lot sizes when compared to 4 levels in the BOM. In fact performance is best for 3 levels in the BOM and the large
lot size which implies that these two effects combine to smooth out variations in the orders. Apparently any "lumpiness" created by large lot sizes are handled better with the longer cumulative production lead times and increased stocking points in an 8 level product, probably because large "lumps" would have more time to be worked through the system and more W-I-P inventory. Alternatively, Figure 9 shows that for large lot sizes and 4 levels in the BOM the performance is worst for this measure. The shorter cumulative lead times and fewer stocking points cannot handle the large "lumps" effectively.

![Graph showing level-lot size interaction for average end item backorders](image)
Specialized work centers (departments) have almost 2-1/2 times as many backorders as its opposite level, which agrees with the alternative hypothesis in Section 3.3, as well as the sample results. As noted in Section 3.2, the number of departments is negatively correlated to the number of items per department, so that for a system with a fixed capacity and number of items, the 4 department case would have more workers per department than the 8 department case and the assignment of workers would be more flexible, too. Consequently, any large orders in the 8 department case would monopolize any one department's capacity and workers much more than in the 4 department case, and a ripple effect would slow down any other items requiring that department, as well as the co-components and parents of those items. Therefore, backorders should increase in this situation, and for the 8 department case it amounted to almost 4 weeks worth of the cumulative average of demand (100 units/week x 4 end items = 400 units/week). Consequently, having more items per department, or a situation where departments are not highly specialized in terms of the products they can make, provides better customer service. By having less work center specialization the risk of breakdowns or work stoppages affecting any one individual product is decreased.

Systems with high end item demand variability or un-
stable MPS have over 6 times as many backorders as a stable MPS, indicated by no end item demand variability, which also agrees with the alternative hypothesis in Section 3.3 and the sample results. The increased variability, which is not smoothed out by the Master Production Schedule, causes "nervousness" in the planning system primarily due to capacity problems. With high demand variability, loads should vary quite significantly with demand if lot-for-lot were being used. However, for FOQ with integer multiples logic, some of this load variability should be smoothed out. Apparently this is occurring, as Table 11 and Figure 10 show.
For the lot size - end item interaction, which is statistically significant, backorders are highest with a small lot size and high demand variability. When demand variability is high, large lot sizes decrease backorders by almost 700 units on average, whereas when there is no demand variability, large lot sizes increase backorders by almost five fold over small lot sizes. With no end item demand variability, large lot sizes could cause poorer backorder performance due to increased "lumpiness" in the system, wherein occasionally large orders for components occur which monopolize the capacity of a department. The number of levels in the BOM would affect this interaction, too. This is similar to what happens when there are specialized work centers. The work center specialization - end item interaction, which is statistically significant, shows in Figure 11 that with specialized work centers and high demand variability backorders are highest. However, for less specialized work centers and no demand variability, backorders are lowest. Consequently, when a system has specialized work centers, management should strive to have as stable of a MPS as possible.
END ITEM DEMAND VARIABILITY

Figure 11
Means of End Item-Work Center Specialization Interaction for the Average Backorders

Figure 12 displays the differences in means for all of the main effects with regard to average cumulative end item backorders.
4.1.3 Average Inventory Units Per Average Item -Y2

This performance measure is the second representative of the general performance of the manufacturing system, and relates to a general objective of management to minimize investment in inventory. A performance objective would be to minimize the value of inventory units,
while still providing satisfactory customer service. Due to the many product and cost structures that companies exhibit, the number of units in inventory is an alternate method of determining inventory investment. In general the average inventory units per average item in the BOM should increase in conjunction with inventory investment.

This sub-section addresses Hypothesis 3 posed in Section 4.1.1. The following discusses Hypothesis 3 for each of the five research factors and their interactions.

An analysis of the F-ratios and powers in Tables 12 and 13 reveals that all of the factors except gateway are significant, with end item demand variability being the most significant (56.5% of total variance) and the number of levels in the BOM the next most significant (14.8% of total variance).

An analysis of the means in Table 14 shows what effect the factors had upon inventory. Four levels in the BOM causes approximately 50% (or 1.3 weeks of demand) more inventory per item to be carried in the system than with 8 levels in the BOM. This result is somewhat surprising and contrary to the alternative hypotheses in Section 3.3 but agrees with the sample results. A possible explanation can be achieved by re-analyzing the results of
the backorder performance for number of levels. For 4 levels in the BOM, both backorders and inventory are higher than with 8 levels, which is unusual since with the increased inventory more orders should be satisfied and end item backorders should be fairly small. For both of these performance measures to have high values, then inventories must be building up for non-critical items in the BOM. Orders would have to be released for many components which are not really needed due to some other critical co-components being delayed. The reason for the critical components being delayed could be temporary overloads in a few departments which handle these items. The 8 level BOM would perform better in this situation, due to a longer cumulative lead time which would increase the likelihood of making up for any delays due to temporary overloads, or possibly just due to the increased number of levels acting like a shock absorber for problems by having more stocking points for work-in-process inventory. The level-lot size interaction is statistically significant and an analysis of the 4 means in Table 11 and Figure 13 shows that having more levels in the BOM is helpful. For example, with 4 levels in the BOM, the difference in means between small and large lot size is 122 units, or 28%, but with 8 levels in the BOM, the difference is only 69 units, or 23%. Comparing Figures 9 and 13 shows one major
Figure 13
Means of Level-Lot Size Interaction for the
Average Inventory Units per Item
difference. For 3 levels in the BOM, smaller lot size has much higher backorders with lower inventory than larger lot size. For 4 levels in the BOM, smaller lot size has lower backorders and inventory than larger lot size. With 4 levels in the BOM the system apparently has a high inventory of non-critical parts, and a low inventory of critical parts.

The other three significant factors had means that agreed with the alternative hypothesis in Section 3.3. More specialized work centers had more inventory units than less specialized work centers. Since for backorder performance the same result occurred, a relationship similar to the number of levels in the BOM must be occurring between these two performance measures and the degree of work center specialization. With more specialized work centers the likelihood of some critical components getting delayed in one or two departments should be greater than with less specialized work centers since large orders could monopolize any one department's capacity more easily. The same situation occurs again for end item demand variability. With high variability in demand the likelihood of having the wrong items in inventory would intuitively seem to be greater than with no variability due to problems with accurate predictions of
future order size. Since the lot sizes are calculated based upon a constant demand rate, any variation from this rate would disturb the whole planning system, and the order sizes would be changing quite often so that remnants could be large overall but various components still could be out of stock. An analysis of the means for the level-end item interaction in Table 11 and Figure 14 shows that end item demand variability has a strong effect upon Y2. Also, this factor when coupled with 4 levels in the BOM has a significant negative effect upon Y2. By having more levels in the BOM the inventory of the parent items in the upper levels could act as a buffer to reduce the effects of end item demand variability on the lower level components. When there are fewer levels the demand variability would have a greater effect upon the lower level components. Therefore, when the MPS is unstable, increasing the number of levels is much more beneficial than when the MPS is stable.

Figure 15 displays the difference in means for all of the main effects with regard to the average inventory units per average item.
Figure 14
Means of Level-End Item Interaction for the Average Inventory Units

Figure 13
Means of the Main Effects for the Average Inventory Units

1 - # of levels in BOM
2 - W.C. specialization
3 - Lot size
4 - End item demand variability
5 - Gateway

LEVEL OF THE RESEARCH FACTOR
4.2.4. **Average Inventory Units - Y7**

This is the third system performance measure and as noted in Section 3.4.1. is confounded with the number of levels in the BOM. However, if a product designer for a given product creates more subassemblies and inventory "stocking points" than might be needed, thereby creating more levels in the BOM, Y7 would be a better measure of inventory performance than Y2.

This subsection addresses Hypothesis 4 of Section 4.1.1 in terms of four of the research factors and their interactions.

An analysis of the F-ratios and powers in Tables 12 and 13 shows that the number of levels in the BOM (41.1% of total variance), and end item demand variability (31.3% of total variance) are the most significant effects, with the degree of work center specialization and the magnitude of the lot size also being significant.

An analysis of the means in Table 14 confirms the alternative hypotheses in Section 3.3 for the significant factors. Also the results agree with the sample results. Except for the number of levels in the BOM factor, the results of the main effects on Y7 are basically the same as on Y2, and the same arguments can apply. As the number of levels increase in this study, generally so do the number of items. Consequently, 8
levels in the BOM should have more inventory units than 4 levels in the BOM, and this is what occurs in Table 14. The level-end item interaction is statistically significant, and the means are displayed in Table 11 and Figure 16. There does not seem to be any large interaction effect occurring between these two factors for this performance measure.

Figure 15
Means of Level-End Item Interaction for the Average Inventory Units
The work center specialization-end item demand interaction is also statistically significant and the means are displayed in Table 11 and Figure 17. Specialized work centers in combination with high end item demand variability causes the poorest performance for this measure, as it did for the backorder measure (see Figure 11). Apparently the system encounters severe load problems with greater departmental specialization and increased end item demand variability. As can be seen in Table 11 the work center specialization-end item interaction is statistically significant on three of the load measures: Y3, Y4, and Y6. The means for these three measures exhibit the same behavior as did Y1 and Y7. Any variability in demand in this situation really degrades the performance of the system.

![Graph showing interaction between fewer items per department, more items per department, and end item demand variability.](image)

**Figure 17**

*Means of End Item-Items Interaction for the Average Inventory Units per Item*
Figure 18 displays the difference in means for all of the main effects with regard to the average inventory units.

![Diagram](image)

Figure 18
Means of the Main Effects for the Average Inventory Units per Item

4.2.5 Average Standard Deviation of the Load Summed over all Departments - Y3

This performance measure is the first of four measures of load variability in the manufacturing system. A contention of this study is that high variability is detrimental to system performance and this hypothesis is tested in Section 4.3.2. Consequently, high values will be considered detrimental in the discussions of the load variability measures.
This sub-section addresses Hypothesis 5 in Section 4.1.1. This performance measure uses load variability taken in each department individually and summed over all departments. The following is a discussion, for each of the five research factors and their interactions pertaining to Hypothesis 5.

An analysis of the F-ratios and powers in Tables 12 and 13 reveals that end item demand variability (78.7% of total variance), the number of levels in the BOM (16.7% of total variance), and the degree of work center specialization (15.7% of total variance) are highly statistically significant with lot size and gateway not being significant.

An analysis of the means shows what effect each factor had upon the standard deviation of the load summed over all departments. All five of the research factors had means which exhibited behavior predicted in the alternate hypotheses in Section 3.3. Eight levels in the BOM had 66% more load deviation in the shop than four levels in the BOM. It is interesting that for the number of levels in the BOM factor system performance was better when load variability was high, but for the other four research factors system performance was poorer when load variability was high. Apparently, having more levels in the BOM creates more load variability which in this case may actually help system performance. If the
planning times are longer, and there are more stocking points in the BOM to act as buffers, load levels could be expected to vary more due to a higher likelihood of changes in both the timing of release and sizing of planned orders to the shop occurring. This greater ability to change planned orders should actually aid system performance. Furthermore, 8 levels has more items in the BOM than does 4 levels, and consequently less specialized work centers, which improve performance. Also, lot size and gateway had means which were different from those in the sample results.

Three of the interaction terms are statistically significant as shown in Tables 10 and 11. The level-end item interaction, with the means graphed in Figure 19, shows some interesting results. For no end item demand variability, 8 levels causes 50% more load variability than 4 levels in the BOM. However, for high end item demand variability, 8 levels causes 75% more load variability than 4 levels in the BOM. Comparing Figure 19 to Figure 14, it is apparent that average inventory units per average item and the average standard deviation of the load summed over all departments exhibit exactly opposite behaviors for this interaction. Consequently, having high end item demand variability
increases inventory and load variability, while 8 levels in the BOM decreases inventory and increases load variability. This agrees with what occurred for the main effects relative to these measures.

Figure 19
Means of Level-End Item Interaction for the Average Standard Deviation of the Load Summed over all Departments
The work center specialization-end item interaction also is significant, and the means are graphed in Figure 20. More specialized work centers and high end item demand variability causes the most load variability. This agrees with the average backorder performance for this interaction (see Figure 11). Where there are more specialized work centers the system is much less able to handle high end item demand variability than when there are less specialized work centers. Load variability and backorders increase disproportionately in this setting.

Figure 20
Means of End Item-Work Center Specialization Interaction for the Average Standard Deviation of the Load Summed over all Departments
The lot size-end item interaction is the last significant interaction for this performance measure, and the means are displayed in Figure 21. For no end item demand variability, large lot sizes increase load variability by 74% versus small lot sizes. However, for high end item demand variability, large lot sizes decrease load variability by 6% versus small lot sizes. For no demand variability large lot sizes cause "lumpiness" in the system and create problems. For high demand variability the large lot sizes should tend to absorb or buffer the variations in demand and decrease the strong effects of the demand variability. This is clearly what is happening when end item backorder performance is considered also, as shown in Figure 10. With small lot sizes the system could not react adequately to any large changes in demand. During periods of high demand many orders would be released to the shop which would increase the load above capacity limits and decrease system-performance. End item backorders would grow as the shop became more and more overtaxed. As the backlog in the shop grew, new orders released to the shop would grow in size due to previous backorders and take more time to complete, thus slowing down the system even more.
Figure 21

Means of the End Item-Lotsize Interaction for the Average Standard Deviation of the Load Summed over all Departments

Figure 22 displays the difference in means for all the main effects with regard to the average standard deviation of the load summed over all departments.

Figure 22

Means of Main Effects for the Average Standard Deviation of the Load Summed over all Departments
4.2.6 *Autocorrelation of the Weekly Loads Summed over all Departments - Y4*

This performance measure is the second measure of load variability in this study and analyzes the length of periods of overloads and underloads measured in each department individually and then summed over all departments. Prolonged periods of over or underloads would be detrimental to manpower planning.

This sub-section addresses Hypothesis 6 in Section 4.1.1, discussing each of the five research factors and their interactions pertaining to this hypothesis.

An analysis of the F-ratios and powers in Tables 12 and 13 shows that the results for this performance measure are very similar to the results for the average standard deviation of the load summed over all departments. End item demand variability (33.7% of total variance), the degree of work center specialization (14.0% of total variance), and the number of levels in the BOM (12.5% of total variance) are the only factors statistically significant again, and the means for each level of the factors display the same general effects as can be seen by comparing Figures 22 and 23.
Figure 23
Means of the Main Effects for the Autocorrelation of the Weekly Loads Summed over all Departments

The significant interaction terms are also the same for both measures and have very similar performance. The lot size-end item interaction showed that with low end item demand variability, the small lot sizes performance for both measures is much better than with a
large lot size. However with high end item demand variability the large lot sizes performance is slightly better than the small lot sizes. Figure 24 displays the means for this interaction on this performance measure.

![Figure 24](image)

**Figure 24**

Means of End Item-Lot Size Interaction for the Autocorrelation of the Weekly Loads Summed over all Departments

The level-end item interaction, whose means are displayed in Figure 25, shows that 8 levels in the BOM and high end item demand variability causes the highest load variability.

![Figure 25](image)

**Figure 25**

Means of Level-End Item Interaction for the Autocorrelation of the Weekly Loads Summed over all Departments
The work center specialization-end item interaction is also statistically significant, and the means are graphed in Figure 26. Once again high end item demand variability in conjunction with more specialized work centers causes the highest load variability, having over 3-1/2 times more load variability than the no end item demand variability and less specialized work centers case.

![Graph showing interaction effects]

**Figure 26**

*Means of End Item-Work Center Specialization Interaction for the Autocorrelation of the Weekly Loads Summed over all Departments*
4.2.7 Average Standard Deviation of the Load Across the Shop - Y5

This performance measure is the third measure of load variability in the manufacturing system, and is computed as if the production shop is comprised of only 1 large department for which load variability is measured. As was mentioned in Section 4.2.5, a comparison of load variability measured across the shop as a whole versus measuring each department individually and summing over them all is another point of interest in this research.

This sub-section addresses Hypothesis 7 in Section 4.1.1. The following is a discussion for each of the five research factors and their interactions pertaining to this hypothesis.

An analysis of the F-ratios and powers in Tables 12 and 13 shows that end item demand variability is the most significant factor statistically (22.9% of total variance) with the number of levels in the BOM also being significant (9.9% of total variance). The only other significant effect is the lot size-end item demand variability interaction. The means in Table 14 show that for both of the significant factors, a larger number of levels in the BOM and high end item demand variability display high values for this performance
measure, which would agree with the alternative hypothesis in Section 3.3. Figure 27 displays the difference in means for all of the main effects with regard to this performance measure.

![Graph](image)

**Figure 27**
Means of the Main Effects for the Average Standard of the Load Across the Shop
The means for the lot size-end item demand variability interaction behaved similarly for this measure as they had for Y3 and Y4, and are graphed in Figure 28. For smaller lot sizes and higher end item demand variability, performance for this measure is the poorest. This result would support the findings in Section 4.2.5 which stated that smaller lot sizes, when combined with higher end item demand variability, would cause more problems with overloads and underloads. Also, for small lot sizes, having high end item demand variability increased load variability 4-1/2 times; whereas, for large lot sizes, having high end item demand variability only increased load variability by 1-1/2 times more than having no end item demand variability.

![Figure 28](image)

Means of End Item-Lot Size Interaction for the Average Standard Deviation of the Load Across the Shop
4.2.8 Autocorrelation of the Weekly Loads Across the Shop-Y6

This performance measure is the fourth representative of load variability in the manufacturing system. The length of periods of overload and underload measured across the shop as a whole is the criterion of interest.

This sub-section addresses Hypothesis 8 in Section 4.1.1, and the following is a discussion for each of the five research factors and their interactions pertaining to this hypothesis.

An analysis of the F-ratios and powers in Tables 12 and 13 shows that end item demand variation is highly statistically significant (33.1% of total variance), with the number of levels in the BOM (12.1% of total variance), and the degree of work center specialization (10.1% of total variance) being the only other significant main effects. Figure 29 displays the means of all of the main effects for this performance measure.
Figure 29
Means of Main Effects for the Autocorrelation of the Weekly Loads Across the Shop
Table 11 shows the means for the significant interactions. The lot size-end item interaction is similar to the results for the other 3 load measures, and is graphed in Figure 30. Once again small lot sizes with high end item demand variability exhibits the worst performance for this measure, while small lot sizes with no end item demand variability exhibits the best performance.

![Graph showing lot size vs. end item demand variability](image)

**Figure 30**

Means of End Item-Lot Size Interaction for the Autocorrelation of the Weekly Load Across the Shop

The level-end item interaction's means are displayed in Figure 31. Eight levels in the BOM with high end item demand variability causes a disproportionate increase in load variability. Similar findings
for this interaction's effect on Y3 were previously discussed in Section 4.2.5.

![Graph showing high and no end item demand variability](image)

**Figure 31**

Means of Level-End Item Interaction for the Autocorrelation of the Weekly Load Across the Shop

The work center specialization-end item interaction is also statistically significant, and the means are graphed in Figure 32. Specialized work centers with high end item demand causes the highest load variability. Similar findings for this interaction's effect on Y3 also were previously discussed in Section 4.2.5.
An analysis of the means in Tables 14, as well as Figures 23, 24, 24, 28 and 30, reveals that this performance measure exhibits relationships between the means of the research factors basically the same as the other 3 load variability measures. More levels in the BOM, specialized work centers, and higher end item demand variability all cause increased load variation and longer periods of overloads and underloads. These results agree with the alternative hypotheses in Section 3.3. Large lot sizes and gateway departments increased load variability moderately, but the results are not statistically significant. The results also
are very similar to the results of the sample experiment. The only change is in terms of the lot size effect, with large lot sizes causing more load variability in the main experiment, but less in the sample experiment. This can be explained by the affects of the lot size-end item interaction, which is statistically significant on all four load measures. For this interaction small lot sizes performed best with no end item demand variability, but worst with high end item demand variability. The sample experiment included this interaction as an alias to one of the main effects (see Appendix D) and the analysis could not be as powerful as the main experiment's analysis.

4.3 Interrelationships of the Primary Performance Measures

The primary performance measures and the effects that the research factors have upon them were discussed in the previous section. This section discusses various interrelationships among the performance measures. Section 4.3.1 addresses Hypothesis 9, regarding the effectiveness of two methods of measuring load variability in the shop. Section 4.3.2 addresses Hypotheses 10 which analyzes the effect load variability has upon system performance.
Table 15 displays the factorial discriminant rankings of the performance measures in relation to the 4 significant research factors. The rankings are computed for all seven performance measures on each of the research factors. The rankings are columnar in nature, with each factor having 7 values, one for each of the seven performance measures. The larger the absolute value a performance measure has, the better the performance measure is able to discriminate between the levels of that factor. Consequently, for each column a ranking of performance measures can be ascertained in terms of the ability of that performance measure to discriminate between levels of that factor. All values in the table are standardized.

Table 16 displays correlation coefficients, or Pearson product-moment correlation coefficient, for all possible two-way combinations between the 3 system and 4 load variability performance measures. The coefficient describes the strength of association between pairs of variables assumed to have some type of relationship. The coefficient can range between -1 and +1, with a negative one denoting perfect negative correlation, a positive one denoting perfect positive correlation, and zero denoting no association or relation. Consequently, the larger the absolute value of a coefficient, the
<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>LEVEL</th>
<th>ITEMS</th>
<th>LOT</th>
<th>END ITEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>-0.64</td>
<td>-0.03</td>
<td>0.63</td>
<td>0.03</td>
</tr>
<tr>
<td>Y2</td>
<td>-0.97</td>
<td>-0.04</td>
<td>-0.45</td>
<td>0.25</td>
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<tr>
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<td>4.39</td>
<td>-13.96</td>
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<tr>
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<td>26.12</td>
</tr>
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<td>2.97</td>
<td>5.63</td>
<td>-4.85</td>
</tr>
<tr>
<td>Y6</td>
<td>2.57</td>
<td>11.56</td>
<td>-1.93</td>
<td>1.69</td>
</tr>
<tr>
<td>Y7</td>
<td>1.44</td>
<td>-0.05</td>
<td>-0.85</td>
<td>1.46</td>
</tr>
</tbody>
</table>
Table 16

Correlation Coefficients of Primary Performance Measures in Main Experiment

<table>
<thead>
<tr>
<th></th>
<th>Y1</th>
<th>Y2</th>
<th>Y3</th>
<th>Y4</th>
<th>Y5</th>
<th>Y6</th>
<th>Y7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>1.00000</td>
<td>0.73074</td>
<td>0.67489</td>
<td>0.71504</td>
<td>0.68750</td>
<td>0.71834</td>
<td>0.38849</td>
</tr>
<tr>
<td>Y2</td>
<td>0.73074</td>
<td>1.00000</td>
<td>0.36044</td>
<td>0.40643</td>
<td>0.29489</td>
<td>0.39960</td>
<td>0.27831</td>
</tr>
<tr>
<td>Y3</td>
<td>0.67489</td>
<td>0.36044</td>
<td>1.00000</td>
<td>0.99643</td>
<td>0.90208</td>
<td>0.99035</td>
<td>0.87564</td>
</tr>
<tr>
<td>Y4</td>
<td>0.71504</td>
<td>0.40643</td>
<td>0.99643</td>
<td>1.00000</td>
<td>0.91053</td>
<td>0.99602</td>
<td>0.85609</td>
</tr>
<tr>
<td>Y5</td>
<td>0.68750</td>
<td>0.29489</td>
<td>0.90208</td>
<td>0.91053</td>
<td>1.00000</td>
<td>0.93857</td>
<td>0.72517</td>
</tr>
<tr>
<td>Y6</td>
<td>0.71834</td>
<td>0.39960</td>
<td>0.99035</td>
<td>0.99602</td>
<td>0.93857</td>
<td>1.00000</td>
<td>0.84114</td>
</tr>
<tr>
<td>Y7</td>
<td>0.38849</td>
<td>0.27831</td>
<td>0.87564</td>
<td>0.85609</td>
<td>0.72517</td>
<td>0.84114</td>
<td>1.00000</td>
</tr>
</tbody>
</table>
stronger the relationship between the two performance measures.

4.3.1 **Factorial Discriminant Analysis**

A factorial discriminant analysis was performed upon the seven performances measures for each of the four significant research factors. This section will utilize those results in order to make comparisons between two sets of the load variability performance measures. The objective is to determine if load variability measured across the shop as a whole discriminates between levels of the significant research factors better than load variability measured for each individual department and then summed. The question of which method is a better predictor of system performance is addressed in Section 4.3.2. If one method is superior to the other then data collection and analysis can be simplified in future research on the subject of load variability.

An analysis of Table 15 proves informative. Two sets of comparisons for each research factor that had a statistically significant effect upon the performance measures are relevant. The absolute ranking values of the load variability performance measures are the criteria of importance for these comparisons. The first
comparison would be for Y3 versus Y5, and the second comparison would be for Y4 versus Y6.

<table>
<thead>
<tr>
<th></th>
<th>Y3</th>
<th>Y5</th>
<th>Y4</th>
<th>Y6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>7.61</td>
<td>3.68</td>
<td>9.09</td>
<td>2.57</td>
</tr>
<tr>
<td>Items</td>
<td>2.26</td>
<td>2.97</td>
<td>12.32</td>
<td>11.56</td>
</tr>
<tr>
<td>Lot</td>
<td>4.39</td>
<td>5.63</td>
<td>7.81</td>
<td>1.93</td>
</tr>
<tr>
<td>End Item</td>
<td>13.96</td>
<td>4.85</td>
<td>16.12</td>
<td>1.69</td>
</tr>
</tbody>
</table>

Y3 and Y5 each have higher rankings twice, but Y4 has higher rankings than Y6 all 4 times. Consequently, the load across the shop measures had lower rankings than the load summed over all departments measures six out of eight times. Therefore, load variability measured across the shop as a whole discriminates more poorly between the levels of the significant research factors than load variability measured for each department and summed. Also a comparison of all four load measures shows that Y4 had the highest rankings on all of the research factors, and appears to be the best discriminating load variability measure.

4.3.2 Correlation Analysis

A correlation analysis was performed upon the seven performance measures which involved Pearson product-moment correlations between three system performance measures and the four load variability measures. This section will utilize those results, which appear in Table 16, the factorial
discriminant analysis rankings in Table 15, and the means of the research factors' levels in Tables 11 and 14 to analyze the relationship between system performance measures and load variability measures. One of the contentions of this research is that high load variability occurs when system performance is poor. Therefore, if high load variability occurs, the two system performance measures' means should be large and a high correlation should exist between the two sets of measures. This subsection addresses Hypotheses 9 and 10 posited in Section 4.1.1. Hypothesis 9 will be discussed first. An analysis of Table 16 proves interesting. In terms of end item backorder performance all four of the load variability measures have fairly large correlations and all are highly statistically significant. The range is between .675 and .718 for these correlations. These correlations probably would have been higher except that the number of levels in the BOM factor have high backorders when load variability is low, which is the opposite of the relationship that the other research factors have. This relationship was discussed in Section 4.2.5, wherein it was hypothesized that for more levels in the BOM, high load variability may be beneficial to system performance. For the other significant factors, however, high load variability occurred with high end item backorders.
For the average inventory units per average item measure the correlations were not nearly as high, though still statistically significant, ranging from .295 to .406. An analysis of the means for each level of the research factors in Tables 11 and 14 shows that once again, except for the number of levels in the BOM, average inventory units per average item and the load variability measures exhibit similar behavior.

For the average inventory units measure the correlations are all highly statistically significant, ranging from .725 to .876. The means in Tables 11 and 14 exhibited similar behavior on all factors for average inventory units and the 4 load variability measures.

In summary, except for the number of levels in the BOM factor, load variability and system performance are relatively high positively correlated for the significant research factors. Therefore, control of load variability should be an important objective of management in order to have better system performance.

Hypothesis 10 will now be discussed. In Section 4.3.1 the relationship between the two sets of load
variability measures was discussed, and the conclusion was that in terms of the factorial discriminant analysis rankings load variability measured at each individual department and summed performed better than load variability measured across the entire shop. Also, Y4 appeared to be the best discriminator between levels of the significant research factors. In terms of the correlation results in Table 16 these same findings are also substantiated. Table 17 displays the comparisons between these two sets of measures.

Table 17

Comparison of Correlation Coefficients of Load Variability Measures

<table>
<thead>
<tr>
<th></th>
<th>Y3</th>
<th>Y5</th>
<th>Diff</th>
<th>Y4</th>
<th>Y6</th>
<th>Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>.675</td>
<td>.688</td>
<td>-.013</td>
<td>.715</td>
<td>.718</td>
<td>-.003</td>
</tr>
<tr>
<td>Y2</td>
<td>.360</td>
<td>.295</td>
<td>.065</td>
<td>.406</td>
<td>.400</td>
<td>.006</td>
</tr>
<tr>
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<td>.876</td>
<td>.725</td>
<td>.151</td>
<td>.856</td>
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<td>.015</td>
</tr>
</tbody>
</table>

In four out of six comparisons the measures across the shop have lower coefficients than the measures summed over all departments. However, the differences are relatively small in magnitude. Based on the results of Section 4.3.1 and Table 17, load variability
measured at each department and summed is a better predictor of system performance than load variability measured across the shop. Consequently, future researchers should use either Y3 or Y4 to measure load variability effectively. The autocorrelation of the weekly loads summed over all departments (Y4) appears to be the best of these two measures.

4.4 Summary

In summarizing the results of multivariate analysis, it was found that all of the research factors are statistically significant (at the .001 level) except for the gateway effect (gateway was significant at the .12 level). It is concluded that the number of levels in the BOM, the degree of work center specialization, the magnitude of the lot size, and end item demand variability significantly affect the 7 performance measures. The level-lot size, level-end item, work center specialization-end item, and lot size-end item interactions also have significant effects upon the 7 performance measures.

Tables 18-22 summarize the results of each research factors effects upon the seven performance measures.

The number of levels in the BOM has a significant effect upon each of the seven performance measures as shown in Table 18. Surprisingly, 4 levels in the BOM has much higher backorders and average inventory units
Table 18
Summary of Statistics For The # of Levels in BOM

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>4 Levels Means</th>
<th>8 Levels Means</th>
<th>Univariate F-Ratio</th>
<th>Power of the Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>1418</td>
<td>768</td>
<td>11.56**</td>
<td>.99</td>
</tr>
<tr>
<td>Y2</td>
<td>381</td>
<td>252</td>
<td>105.59**</td>
<td>.99</td>
</tr>
<tr>
<td>Y3</td>
<td>283</td>
<td>470</td>
<td>33.07**</td>
<td>.99</td>
</tr>
<tr>
<td>Y4</td>
<td>720</td>
<td>1169</td>
<td>24.32**</td>
<td>.99</td>
</tr>
<tr>
<td>Y5</td>
<td>113</td>
<td>209</td>
<td>10.92**</td>
<td>.99</td>
</tr>
<tr>
<td>Y6</td>
<td>552</td>
<td>902</td>
<td>19.76**</td>
<td>.99</td>
</tr>
<tr>
<td>Y7</td>
<td>11694</td>
<td>26146</td>
<td>197.52**</td>
<td>.99</td>
</tr>
</tbody>
</table>

MANOVA $F_{27} = 124.62$
### Table 19

**Summary of Statistics for Degree of Work Center Specialization**

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Less Specialized</th>
<th>More Specialized</th>
<th>Univariate F-Ratio</th>
<th>Power of the Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>630</td>
<td>1556</td>
<td>23.41**</td>
<td>.99</td>
</tr>
<tr>
<td>Y2</td>
<td>297</td>
<td>337</td>
<td>10.19**</td>
<td>.99</td>
</tr>
<tr>
<td>Y3</td>
<td>286</td>
<td>467</td>
<td>31.06**</td>
<td>.99</td>
</tr>
<tr>
<td>Y4</td>
<td>707</td>
<td>1182</td>
<td>27.23**</td>
<td>.99</td>
</tr>
<tr>
<td>Y5</td>
<td>136</td>
<td>186</td>
<td>2.96</td>
<td>.56</td>
</tr>
<tr>
<td>Y6</td>
<td>567</td>
<td>887</td>
<td>16.54**</td>
<td>.99</td>
</tr>
<tr>
<td>Y7</td>
<td>16448</td>
<td>21392</td>
<td>23.11**</td>
<td>.99</td>
</tr>
</tbody>
</table>

**MANOVA** $F_{27}^7 = 74.49$

$F_{.05} = 4.15^*$

$F_{.01} = 7.51^*$
Table 20

Summary of Statistics For Magnitude
Of The Lot Size.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Small Lot Size Means</th>
<th>Large Lot Size Means</th>
<th>Univariate F Ratio</th>
<th>Power of the Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>1170</td>
<td>1017</td>
<td>0.64</td>
<td>.08</td>
</tr>
<tr>
<td>Y2</td>
<td>269</td>
<td>365</td>
<td>58.92**</td>
<td>.99</td>
</tr>
<tr>
<td>Y3</td>
<td>350</td>
<td>403</td>
<td>2.71</td>
<td>.53</td>
</tr>
<tr>
<td>Y4</td>
<td>875</td>
<td>1014</td>
<td>2.32</td>
<td>.44</td>
</tr>
<tr>
<td>Y5</td>
<td>180</td>
<td>142</td>
<td>1.70</td>
<td>.32</td>
</tr>
<tr>
<td>Y6</td>
<td>685</td>
<td>769</td>
<td>1.14</td>
<td>.19</td>
</tr>
<tr>
<td>Y7</td>
<td>16619</td>
<td>21221</td>
<td>20.02**</td>
<td>.99</td>
</tr>
</tbody>
</table>

MANOVA $F_{27} = 55.41$
Table 21

Summary of Statistics for End Item Demand Variability

<table>
<thead>
<tr>
<th>Product Variable</th>
<th>No Variability Means</th>
<th>High Variability Means</th>
<th>Univariate F Ratio</th>
<th>Power of the Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>297</td>
<td>1889</td>
<td>69.23**</td>
<td>.99</td>
</tr>
<tr>
<td>Y2</td>
<td>191</td>
<td>442</td>
<td>402.87**</td>
<td>.99</td>
</tr>
<tr>
<td>Y3</td>
<td>255</td>
<td>499</td>
<td>56.75**</td>
<td>.99</td>
</tr>
<tr>
<td>Y4</td>
<td>577</td>
<td>1312</td>
<td>65.45**</td>
<td>.99</td>
</tr>
<tr>
<td>Y5</td>
<td>88</td>
<td>234</td>
<td>25.28**</td>
<td>.99</td>
</tr>
<tr>
<td>Y6</td>
<td>437</td>
<td>1017</td>
<td>54.13**</td>
<td>.99</td>
</tr>
<tr>
<td>Y7</td>
<td>12610</td>
<td>25230</td>
<td>150.60**</td>
<td>.99</td>
</tr>
</tbody>
</table>

MANOVA $F_{27} = 154.71$

$F_{.05} = 4.15^*$

$F_{.01} = 7.51^{**}$
### Table 22

**Summary of Statistics for The Gateway Department**

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>No Gateway Means</th>
<th>Gateway Means</th>
<th>Univariate F-Ratio</th>
<th>Power of the Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>1047</td>
<td>1139</td>
<td>0.23</td>
<td>.03</td>
</tr>
<tr>
<td>Y2</td>
<td>312</td>
<td>322</td>
<td>0.64</td>
<td>.08</td>
</tr>
<tr>
<td>Y3</td>
<td>367</td>
<td>386</td>
<td>0.37</td>
<td>.05</td>
</tr>
<tr>
<td>Y4</td>
<td>914</td>
<td>975</td>
<td>0.45</td>
<td>.06</td>
</tr>
<tr>
<td>Y5</td>
<td>143</td>
<td>179</td>
<td>1.50</td>
<td>.26</td>
</tr>
<tr>
<td>Y6</td>
<td>696</td>
<td>758</td>
<td>0.62</td>
<td>.08</td>
</tr>
<tr>
<td>Y7</td>
<td>18232</td>
<td>19608</td>
<td>1.79</td>
<td>.29</td>
</tr>
</tbody>
</table>

**MANOVA** $F_{27} = 1.85$

$F_{.05} = 4.15$

$F_{.01} = 7.51$
per average item than 8 levels in the BOM. However, load variability is higher for 8 levels in the BOM, as are the average inventory units. Apparently higher load variability may be caused by more replanning of orders or by the larger number of items in the 8 level BOM. These relationships are also present for the level-lot size and level-end item interactions.

Table 19 shows that the degree of work center specialization has a significant effect upon all of the performance measures except the standard deviation of the load across the shop (Y5). In all cases performance is much poorer for more specialized work centers. When there are many changes in orders occurring, a department with fewer types of items that it can work on has fewer options for rescheduling work and performance should decrease. This is verified by the work center specialization - end item interaction's effects upon five of the performance measures. The means for high end item demand variability and more work center specialization are anywhere from 108% to 374% larger than the means for no end item demand variability and more work center specialization for the seven performance measures.
Table 20 shows that the magnitude of the lot size has a significant effect only upon the two inventory measures (Y2 and Y7). Large lot sizes had higher inventory than small lot sizes. Load variability generally is higher for large lot sizes, also. The level-lot size and lot size-end item interactions have interesting results. In terms of backorders, large lot sizes and eight levels in the BOM have a mean about one third the size of large lot sizes and 4 levels in the BOM, and less than one half the size of the means for the small lot size. Consequently large lot sizes should be used with 8 levels in the BOM and small lot sizes used with 4 levels in the BOM for best performance in terms of backorders. For high end item demand variability large lot sizes perform better, while for no end item demand variability small lot sizes perform better. For best performance for the average inventory units per average item small lot sizes should be utilized with either 4 or 8 levels in the BOM. In terms of the 4 load variability measures, once again small lot sizes have the best performance for no end item demand variability and the worst performance for high end item demand variability.

End item demand variability has a significant effect upon each of the performance measures as shown in
Table 21. Performance is always much worse for an unstable MPS. The system could not adequately cope with large fluctuations in end item demand. However interactions with the other factors show that this severe degradation of system performance can be lessened in certain situations. For backorders and average inventory units per average item 8 levels in the BOM, large lot sizes and less specialized work centers are best if high demand variability is present. For no demand variability, 8 levels in the BOM, small lot sizes, and less specialized work centers are best. For the four load variability measures 4 levels in the BOM, less work center specialization, and large lot sizes are best for high demand variability. For no demand variability 4 levels in BOM, less work center specialization, and small lot sizes are best for performance. For the average inventory units measure 4 levels in the BOM, less work center specialization, and small lot sizes are best for demand variability levels. Conversely, if a multistage, multi-product company has specialized work centers, few levels in the BOM, and large lot sizes then achieving as stable of a MPS as possible would be their best strategy to improve system performance.

The gateway factor is not statistically significant for any of the performance measures, as Table 22 shows.
Neither are any of its interactions significant. However, the means for all of the performance measures are higher for shops with gateway department, though the differences in means are not large (about 6%).

Analyses of relationships between the performance measures have been performed. Load variability measured at each department and summed is a better predictor of system performance that load variability measured across the shop. Overall the autocorrelation of the weekly loads summed over all departments is the best load variability measure. The load variability measures are highly correlated to the system performance measures. Except for the number of levels in the BOM factor the two sets of measures are positively correlated. Therefore, achieving low load variability should increase system performance.

In this chapter research hypotheses were posed in Section 4.1 and addressed in Sections 4.2 and 4.3. These hypotheses focused on the impact that the main experimental research factors and their interactions have upon the primary performance measures, and upon relationships among the primary performance measures. An overall assessment of this research is provided in the concluding chapter.
CHAPTER V
SUMMARY AND CONCLUSIONS

In this chapter a synthesis of this research is presented. An overview of the nature of the problem, the strategy used to analyze the problem, the results obtained from the experiments, and the conclusions from the analysis performed. Furthermore, this research is compared and discussed in relation to previous relevant research of a similar nature. Also addressed is how the results of this study can help improve the design and effectiveness of multi-stage production systems. However, as in any theoretical model, the transfer of the results obtained from the model to an actual manufacturing setting is not without problems; therefore, the limitations of this study are discussed. The final section of this chapter identifies some of the possible areas for future research.
5.1 Summary

In this study a complex simulation model is used to analyze the impact that seven research factors have upon load variability and the performance of multistage, multiproduct manufacturing systems. Excessive load variability is generally considered detrimental to system performance by causing increased overtime, undertime, expediting and replanning costs, as well as decreased customer service. Several techniques are available for reacting to load variability once it occurs, but these can be complex and expensive to use. Consequently, this research attempts to circumvent the need for such techniques by identifying specific factors that affect load variability. Then production planners and managers can design and operate their systems accordingly so as to achieve the best performance possible.

The seven research factors were chosen from a set of variables considered to have possible effects upon load variability. The factors are the number of levels in the BOM, the degree of work center specialization, the magnitude of the lot size, the amount of end item demand variability, the use of a gateway department, priority rules, and the average load on the system. All of these factors are totally or partially controllable by the management of a firm.
Two sets of performance measures have been selected for this study. The first set measures the performance of the production system and includes the average cumulative end item backorders, the average inventory units per average item, and the average inventory units. A reduction in each measure is considered advantageous to the effectiveness of the system. The second set measures two aspects of load variability: the magnitude of variability and the length of periods of overloads and underloads. The measures are the average standard deviation of the load across the shop, the autocorrelation of the weekly loads across the shop, the average standard deviation of the load summed over all departments, and the autocorrelation of the weekly loads summed over all departments. Measuring across the shop, and measuring and summing over all departments are included in order to determine if one method is more effective at measuring load variability than the other.

The research is divided into two parts. The first phase involved a fractional factorial design so that the main effects could be analyzed. Due to the large number of research factors, any that did not significantly affect the performance measures would not be further analyzed in this study. The average load on the system and the priority rule effects are not statistically significant.
at the .05 level and have not been included in the second phase of this study. For the sample experiment, the Due Date rule had slightly poorer performance than SPT for all but the two inventory measures. An average load of 85% had slightly poorer performance than an average load of 90% on all performance measures except for the average inventory units per average item and the average standard deviation of the load summed over all departments. This discrepancy is probably due to the fractional factorial design and small sample size.

The main experiment involved a full factorial design with two replications per cell. The five factors and their interactions were analyzed with MANOVA and ANOVA relative to their effects upon the seven performance measures. A comparison of the load variability measures' effectiveness was performed. Also, a correlation analysis between the set of system performance measures and the set of load variability measures was conducted.

The summary of the major results of this study commences with the multicriteria analysis of variance findings. All of the main effects have a highly significant effect on the set of seven performance measures except for the use of gateway departments. Seven of the interactions also are statistically significant.

The number of levels in the BOM is statistically
significant on all seven performance measures. Eight levels in the BOM performed better in terms of average backorders and average inventory units per average item, but poorer for the load measures and average inventory units. Having more levels means having more planned lead time in this study, and this combined with the buffering effect more levels should have upon any "shocks" to the system due to the increased total inventory, accounts for the better backorder performance. Also, the number of items increases with the number of levels, which would increase the number of items per work center and cause less specialization of work centers. Less specialized work centers exhibit better performance in this research, so that the number of levels in the BOM factor's significance may be partially due to this. The higher load variability may be caused by more replanning of orders.

The degree of work center specialization is statistically significant on all performance measures except the standard deviation of the load across the shop. Performance is much poorer for more specialized work centers since the variety of orders to schedule or re-schedule would be lower, and consequently flexibility to handle problem situations should be lower. More specialized work centers when combined with high end
item demand variability performed significantly worse than more specialized work centers in combination with no end item demand variability.

The magnitude of the lot size significantly affected only the two inventory measures, with large lot sizes having more inventory. The level-lot size and lot size-end item interactions are significant also. For best backorder performance, large lot sizes should be used with 8 levels in the BOM, and small lot sizes with 4 levels in the BOM. For best average inventory units per average item performance, small lot sizes should be used with either 4 or 8 levels in the BOM.

End item demand variability, or the stability of the MPS, has a strongly significant effect upon all 7 performance measures, with high variability causing much poorer performance. Companies having unstable MPS's can mitigate the effects somewhat, as the three significant interactions show. For better performance for backorders and average inventory units per average item when demand variability is high, 8 levels in the BOM, less specialized work centers, and large lot sizes should be used. For the four load measures and high demand variability, performance is better with 4 levels in the BOM, less specialized work centers, and large lot sizes. For the average inventory units measure and high demand variability, performance is
best with 4 levels in the BOM, less specialized work centers, and small lot sizes. For the case of no demand variability, performance is best on all measures with less specialized work centers and small lot sizes. Four levels in the BOM is best except for backorder and average inventory units per average item performance. Alternatively, if companies have specialized work centers, small lot sizes, or few levels in the BOM, then stable MPS's are necessary to attain good system performance.

The gateway factor is not statistically significant on any of the performance measures. However, the means for all performance measures are slightly (about 6%) higher for shops with gateway departments.

Several relationships between the performance measures are noteworthy. Load variability measured at each department and summed is a better predictor of system performance than load variability measured across the shop. Overall the autocorrelation of the weekly loads summed over all departments is the best load variability measure. This result is important in terms of simplifying data collection and analysis in future research. The load variability measures are positively correlated to the system performance measures, thus verifying a contention of this research. Better system performance can be obtained when load variability is kept as low as possible.
5.2 Synthesis

Very little research has been conducted on load variability in a MRP oriented production system. Most research has revolved around lot sizing (8), (9), (11), and very little has been done in terms of factors which affect the performance of multistage production systems (22), (64). This research has attempted to rectify both shortcomings by doing an analysis of factors which could affect both issues. This section will briefly relate to the results which were summarized in Section 5.1, to other research, and address the implications of the findings.

There have been very few published studies of load variability in multistage production systems. However, it is generally assumed that high load variability, or periods of long underloads or overloads are detrimental to the functioning of a production system. The findings of this study lend some credence to this hypothesis. For six of the research factors (three were statistically significant), the load variability measures performed poorly for the same level that the system performance measures performed poorly. For instance, for high end item demand variability, backorders and load variability are significantly higher than for no end item demand variability.
Jones (43) has hypothesized and Conway, Maxwell, and Miller (25) have shown that the average load level in a job shop has a significant effect upon the performance of jobs in the system for several different priority rules. This research could find no such relationship. There are two possible reasons: (1) this research utilized a multi-stage production system instead of a job shop; and (2) much more complex and generalized product structures have been utilized. For the sample runs the average load level has no significant effect upon any of the performance measures. Four explanations are possible: (1) no relationship exists; (2) the sample size is too small to discern the relationship; (3) the levels chosen are not far enough apart to differentiate the relationship; and (4) the relationship between the performance measures and average load is dish shaped, so that within a certain range for the load, the performance measures are unaffected, but at the extremes performance decreases. Only further research can determine which of these cases is true, since the findings are based only on the sample runs. The first three explanations could apply to the next two findings also.

Previous multistage research by Berry (7) has shown that priority rules have an effect upon system performance. SPT has performed well in most studies, depending upon
what performance criteria are used. In this study, no statistical difference was found between Due Date and SPT; however, for cumulative end item backorders and the load variability measures, SPT did perform better than Due Date.

Gateway departments have no statistical significance on the performance measures in the main experiment, but are significant on three of the measures in the sample experiment. Shops with gateway departments have much poorer performance in the sample runs, but only slightly poorer performance than non-gateway shops for the main experiment. Further study is necessary on this subject, since gateway departments are used in many manufacturing facilities, and since the sample experiment results showed a significantly strong relationship existed.

Collier's (21) research showed that end item demand variability had no significant effect upon cumulative end item backorders and inventory costs. This research found this factor to be the most highly significant factor on almost all of the performance measures. Several reasons for the discrepancy are possible: (1) this research had a much larger sample of product structures; (2) this research used average inventory units per item instead of any cost parameters; and (3) Collier defined and utilized end item demand variability differently from
this study. The implication of these results about end item demand variability is that utilizing MPS techniques to smooth out demand variations are definitely worthwhile in a multistage environment. The greater variation in the end item gross requirements (demand), the poorer the system performs. Several other options for overcoming this effect are discussed in Section 5.1.

Ritzman, Krajewski, and Bragg (64) analyzed the effect of the magnitude of the lot size in a multistage system and concluded that larger lot sizes using FOQ logic increased inventory costs. This research confirmed their results in terms of number of units carried. Harl (37) found that large lot sizes in conjunction with his research heuristic performed better for backorder performance, but were not significant for inventory costs. This research showed that for 8 levels in the BOM or for high demand variability large lot sizes are better. However, for 4 levels in the BOM or no demand variability small lot sizes are better. This study utilized a much larger sample of product structures and integer multiples of the parent lot size logic for the component parts, so that comparisons should be guarded. Since set up costs were not measured in this study the usage of small lot sizes should be carefully considered in terms of the total cost implications.
The degree of work center specialization has a significant effect upon most of the performance measures. More specialized work centers exhibited poorer performance with system performance and load variability. Consequently, when designing the shop structure and routings for a multi-stage, multiproduct production system, management should have less specialized work centers in order to smooth out load fluctuations and improve system performance. Also, if specialized work centers are necessary, then stability in the MPS is very important.

Ritzman, Krajewski and Bragg (64) also studied the effects that the number of levels in the BOM had upon system performance. Their conclusions were that inventory costs increased as more levels were added to the product structure. This research showed that for the higher number of levels in the BOM end item backorders and the average inventory units per average item decreased significantly. The conflict in inventory results may be due to their small sample size and differing cost structure and performance measures. Harl (37) found, in the first stage of his study, that the number of levels in the BOM in conjunction with his research heuristic had an insignificant effect upon his performance measures. As discussed in Chapter 2, many of his assumptions were different, as was his smaller sample size, from the present
research. The implications of these findings are that, in a system with few (15-20%) common parts, product structure designers and production planners should attempt to design and use product structures that entail more levels. While it may not be possible to redesign some products' structures due to engineering and assembly precedence requirements, other products may have more flexibility, and additional assembly or inventory stocking points can be added.

5.3 Contributions and Limitations

Due to the difficulties of analyzing many different companies, as well as actually being allowed to perform tests on these companies, some form of simulation study was needed in order to develop general guidelines relative to system performance and load variability. Although far from perfect, the guidelines contained in this survey research contribute both to the practitioner and researcher in the area of MRP oriented systems by providing insight and some understanding of this very complex and little researched area.

This study has two major contributions to practitioners in production planning. The first is the determination of a set of general guidelines and conclusions relative to the research factors' effects upon the performance measures. System performance can be improved
by proper design, control, and choice of levels for these factors. The second contribution is the large number and realistic set of product structures analyzed in this study. By taking such a large sample and using a complex and realistic simulation model, the results should be generalizable to a large number of applications.

There are also two major contributions to future researchers in this field. Since four of the research factors appear to significantly affect the performance of the production system, they cannot be ignored in future research. Future researchers must carefully choose the level at which these factors are fixed when analyzing other aspects of MRP oriented production systems. Consequently, this research should help future researchers to better study other important questions without having to include quite as many parameters as research factors. The second contribution is the clarification of the load variability measures. A positive correlation was shown between the load variability and the system performance measures. Consequently, decreasing load variability can be considered as another performance objective. Also the autocorrelation of the weekly loads summed over all departments is considered to be the best load variability measure. Therefore, load variability can be measured effectively
by this single performance measure. Some other contributions are a new set of inventory performance measures that can be utilized on any product or cost structure; the development of a general BOM generator capable of defining and creating very complex product structures from user-specified parameters; and the description of a set of factors (other than the research factors) that could affect load variability and system performance.

Several limitations should be mentioned, including the scope of the problem, the implementation of the study, and the simulation environment from which the results were obtained. The model was constructed so that it corresponded to a defined environmental situation. This situation was designed to include a limited number of factors. It cannot be assumed that all of the complexity of real systems were grasped, especially since important factors had to be excluded to make the problem manageable. A wide variety of environmental situations could deepen the understanding of the system, and therefore, the results would have a higher degree of generalizability. As was discussed in Section 5.2, further research is needed into three of the research factors that had insignificant effects upon the performance measures. While the factors were statistically insignificant in this research setting, they may be important in other
settings. One final limitation would be that no cost measurements were included in this study due to problems comparing between diverse BOM's and determining proper valuations that would be generalizable.

5.4 Extensions

In the introductory chapter of this study, many researchable topics were identified. The area of multi-stage production systems has barely been examined. As mentioned in Chapter II, very little research has been published on the issues of product structure, shop structure, and capacity planning in systems utilizing MRP, and discussion has been primarily limited to the practitioners and consultants in this field.

Several researchable topics were mentioned in the previous section involving the three factors which proved insignificant in this study, as well as further examining the relationship between load variability and system performance for the number of levels in the BOM. By relaxing the assumptions of this research, or by expanding the levels of the research factors, many other avenues of research are available. Some examples would be: (a) analysis of the performance of a labor limited system, especially in regard to the average load on the system; (b) analysis of using different priority rules per department depending upon the average load
variability in the department; (c) the effects of safety stocks on load variability and system performance; (d) the use of alternate routings to smooth load variability; (e) an analysis of the ratio of set up time to operations time per department, and if a balance between departments is useful; (f) the effect that the number of operations per item has upon load variability and system performance; (g) an analysis of system performance throughout the range of average loads; (h) an analysis of the use of different priority rules at bottleneck departments than are used throughout the rest of the system. Any of these issues warrant further research.

Other topics of future research could involve an analysis of feedback systems between MPS and aggregate planning, detailed study of load manipulation procedures, and a more detailed analysis of product structure issues including: the number of parents per item, the number of components per parent, the number of end items in the planning system, replacement parts orders, and the quantity of each component that goes into its parent.
APPENDIX A
MRPSIM Simulation Model

In order to address research problems related to production planning in multistage systems a simulation model called FACTORY V was developed. The original simulation model was developed by S.T. Hardy of The Ohio State University and D. Dukes of Texas Tech University. The model was used by D. Collier (21) in his dissertation research, and a complete description of the simulator appears there. FACTORY V has been revised by D. Bragg, and to a lesser extent by the author, both of The Ohio State University. The basic logic model, and theories behind the simulation have not been changed.

The following is a list of the primary differences between FACTORY V and MRPSIM.

1. Some of the GASP IV subroutines have been removed and/or revised in order to increase computer efficiency and decrease storage.

2. The capacity planning subroutines have been removed, since they were not needed for this study.

3. The simulation was "cleaned up" in general, in terms of more efficient programming and use of arrays, and deletion of unneeded coding.

4. The output phase was revised in order to collect the necessary statistics for this study.

5. The initialization phase was modified slightly so that the inputs from the BOM generator would correspond.
According to Emshoff and Sisson (31), a system can exhibit stable or transient states. A system (simulation model) is said to have reached steady-state (stable) conditions when successive observations of the system's performance are statistically indistinguishable. That is, a system has reached steady-state when the next observation provides no new information about the future behavior of the system. Transient states can occur because of either of the following two reasons: (a) the starting conditions used to initialize the model were atypical of operating conditions, or (b) transient phenomenon are expected. Economic models of the GNP for the United States are examples of expected transient phenomenon. In fact, it is the transient state itself which is studied.

While there are no fixed rules for determining when steady-state conditions are achieved, Emshoff and Sisson (31) suggests the following rules. Compute a moving average of the output and assume steady-state when the average no longer changes significantly over time. Another rule suggested is if the number of observations in which the output is greater than the average to a given point is about the same as the number in which it is less, then steady-state conditions are likely to exist.

As previously noted, one general rule for determining when steady-state conditions are achieved is to compute a moving average of the output and assume steady-state when the average no longer changes significantly over time.
MRPSIM collects the moving average routinely for many of the statistics, so several simulation runs were made for varying lengths of time. The averages were computed at 50 week intervals over a 500 week (2500 days) period. There were no significant differences in the performance data mean values after the first 50 week period, so it was decided that a 250 week planning horizon was adequate to achieve steady-state, still provide enough observations, and not be too costly.

The second procedure consisted of analyzing the output of several simulation runs. The initialization or non-recording period was either 50 or 100 weeks, with the data collection period running for 250 weeks. While there was no difference in the mean values of the performance statistics between the two cases, the 100 week initialization period was chosen due to the use of a large number of different product structures in this research.

Model Validation

Material Requirements Planning is a topic that has received much attention from practitioners due to its great use by many companies. Consequently any simulation study of this topic area should utilize as realistic and valid of a model as possible. The author feels that MRPSIM, in conjunction with the BOM generator, meets these criteria due to its complexity and ability to analyze many product and shop structures.
Several studies have determined general criteria for model evaluation and assessing model validity (66), (72). The following is a summary of these articles in relation to MRPSIM.

1. Documentation - this is defined as written information concerning a model. Descriptive documentation consists of general information about the model such as its underlying theories, assumptions, limitations, constraints, etc. Technical documentation consists of information that is sufficiently detailed to allow technical evaluation of the model, including details of the methodology used, mechanization, and the running the model to permit duplication and operation of the model. In terms of MRPSIM, some descriptive documentation has been provided by Collier in terms of FACTORY V. There is some technical documentation in terms of consent statements in the actual computer program. Currently, several faculty members at The Ohio State University are in the process of documenting MRPSIM.

2. Validity - There are three areas of model validity, each of which will be discussed.

   a. Theoretical Validity - this requires the evaluators to review the theories underlying the model and the major stated and implied assumptions which are embodied in that set of theories. The evaluators must also verify that the transition from the theoretical model of perceived reality to the computer model has been made correctly. This involves identifying and assessing the
reasonableness of the most important assumptions made by the modelers. MRPSIM and FACTORY V should meet these requirements.

b. Data Validity - this involves analyzing the accuracy or ability to correctly identify and measure what is desired, impartiality or correctness of data recording, and representativeness of the data. Because of the BOM generator, the author feels that MRPSIM meets these criteria as closely as possible, especially since real company data has been unavailable.

c. Operational Validity - this is concerned with assessing the importance or effect upon the actual use of the model of errors, divergences, or the inability to predict infallibly the real-world situation. Until real company information is analyzed by MRPSIM, the operational validity of the model is somewhat unclear.

3. Computer Model Verification - this involves ensuring that the model has the attributes it was intended to have and behaves as intended. There must be evidence to establish that:

a. the mathematical and logical relationships are internally consistent

b. the mathematical and numerical results are correct and accurate

c. the logical flow of data and intermediate results are correct

d. the important variables and relationships have been included
e. the computer program accurately describes the model as designed.

f. the program is properly mechanized and debugged

g. the program runs as expected.

The author and two colleagues have used MRPSIM for 18 months prior to this study, and numerous people have examined many of the above aspects, and it is felt that MRPSIM satisfies the above criteria.

The following is a listing of the MRPSIM simulation used in this study. The program is written in FORTRAN, and is compatible with either an IBM 370 or DEC 20 computer system.
COMMON /TIME1,CLOCK,DTIME,PTIME,IDAY,IRUN,INEXK,NCLR,NDAY,NSTOP,
INEXK,INEXK,NSTODAY,3VAL
COMMON /ORDERS/, INDEX(999,3),IDNDRF(999,3),IDNDRF(999,20),NNAVIL,
INDEX(52),INDEX,INDEX,INNAR,ORDER(999,4)
COMMON /STMT/ SAVSEL(10),IDCODE,IX
SUBROUTINE INITIAL READS IN ALL INPUT DATA WHICH SPECIFIES
ALL MODEL PARAMETERS. INITIAL ALSO INITIALIZES ALL VARIABLES
C AND DATA STRUCTURES.
OPEN (UNIT=40, FILE="311.DAT")
OPEN (UNIT=30, FILE="344.DAT")
CALL INITIAL
OPEN (UNIT=40, FILE="311.DAT")
OPEN (UNIT=30, FILE="344.DAT")
CALL INITIAL

C THIS SECTION CONTROLS THE SEQUENCING OF ALL EVENTS WITHIN THE
SIMULATION. THIS MODEL OPERATES WITH TWO BASIC EVENT TYPES.
THE FIRST EVENT IS THE END-OF-DAY EVENT. THIS EVENT PROCESSES
ALL ACTIVITIES WHICH RELATE TO A DAILY TIME FRAME. THIS EVENT
IS PROCESSED BY THE DAILY SUBROUTINE. THE SECOND EVENT IS THE
END-OF-PROCESSING EVENT. THIS EVENT REPRESENTS AN ORDER THAT
HAS JUST FINISHED PROCESSING AT A MACHINE GROUP. THIS EVENT
SEND S THE COMPLETED ORDER TO ITS NEXT OPERATION AND ATTEMPTS
TO START PROCESSING OTHER ORDERS THAT MAY BE WAITING FOR
PROCESS (I.E. WAITING IN QUEUE).

100 IF (PTIME.LT.CLOCK) GOTO 110
2700 IF (PTIME.LT.CLOCK) GOTO 120
2800 C = PTIME
2900 CALL EXPROC
3000 GOTO 100
3100 110 IF (DTIME.LT.CLOCK) GOTO 120
3200 DTIME = DTIME
3300 CALL DAILY
3400 GOTO 100
3500 120 WRITE (3, 5000) CLOCK, DTIME, PTIME
3600 500 FORMAT (A EVENT SEQUENCING ERROR; CLOCK="F10.2," DTIME="F10.2")
3700 23700 STOP
3800 STOP
3900 END
SUBROUTINE INITIAL
4100 INTEGER NPT, FPROD, RECT, SRECT
4200 COMMON /TIME1,CLOCK,DTIME,PTIME,IDAY,IRUN,INEXK,NCLR,NDAY,NSTOP,
4300 INEXK, INEXK,NSTODAY,3VAL
4400 COMMON /LALIAS/, XLAL, XCON, XDEPT, XFIN, XJOBX, XGRD, XLAB, XLOT,
4500 XLAL, XCON, XDEPT, XFIN, XJOBX, XGRD, XLAB, XLOT,
4600 COMMON /PROD1/LW14D(200, 7), LW14D(200, 15), LW14D(993, 5),
4700 LW14D(993, 2), LW14D(993, 2), LW14D(993, 2), LW14D(993, 2),
4800 L1, S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14,
4900 S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S27,
5000 S28, S29, S30, S31, S32, S33, S34, S35, S36, S37, S38, S39, S40,
5100 S41, S42, S43, S44, S45, S46, S47, S48, S49, S50, S51, S52, S53,
5400 S54, S55, S56, S57, S58, S59, S60, S61, S62, S63, S64, S65, S66,
5700 5500 COMMON /PROD1/LW14D(200, 7), LW14D(200, 15), LW14D(993, 5),
5800 LW14D(993, 2), LW14D(993, 2), LW14D(993, 2), LW14D(993, 2),
5900 L1, S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14,
6000 S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S27,
6100 S28, S29, S30, S31, S32, S33, S34, S35, S36, S37, S38, S39, S40,
6200 S41, S42, S43, S44, S45, S46, S47, S48, S49, S50, S51, S52, S53,
6300 S54, S55, S56, S57, S58, S59, S60, S61, S62, S63, S64, S65, S66,
6400 LW14D(200, 7), LW14D(200, 15), LW14D(993, 5),
6500 LW14D(993, 2), LW14D(993, 2), LW14D(993, 2), LW14D(993, 2),
6600 L1, S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14,
6700 S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S27,
6800 S28, S29, S30, S31, S32, S33, S34, S35, S36, S37, S38, S39, S40,
6900 S41, S42, S43, S44, S45, S46, S47, S48, S49, S50, S51, S52, S53,
06100 COMMON /BOTT2/IFLAG(7),JFLAG(3),XFLAG,IDPT,YPGRP,IIPR30,AXLJAD(3)
06200 COMMON /BOTT3/ BORD(200),TLSTD(10),TALO(10),TITAL(7),QUEUE(10),
06300 LNAV(200)
06400 COMMON /BOTT5/ NCT(52),ORD(52),REJ(52),SREQT(52)
06500 DIMENSION MSK(100),ISAVE(30,2),A(2)
06600 C
06700 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
06800 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
06900 C
07000 C THIS SECTION SETS THE LIMITS FOR THE VARIOUS DATA STRUCTURES.
07100 C THESE LIMITS SHOULD REFLECT THE CURRENT SIZE OF THE ARRAYS.
07200 C
07300 C-----------------------------------------------
07400 C
07500 C MALT- MAXIMUM NUMBER OF OPERATIONS (ALL ITEMS).
07600 C MXCM- MAXIMUM NUMBER OF COMPONENTS (ALL ITEMS).
07700 C MXDPT- MAXIMUM NUMBER OF DEPARTMENTS.
07800 C MXFIN- MAXIMUM NUMBER OF FINISHED ITEMS.
07900 C MXJOB- MAXIMUM NUMBER OF JOB SEQUENCING RULES.
08000 C MXGRP- MAXIMUM NUMBER OF MACHINE GROUPS (ALL DEPARTMENTS).
08100 C MXLA- MAXIMUM NUMBER OF LABOR ASSIGNMENT RULES.
08200 C MXLJ- MAXIMUM NUMBER OF LJT SIZE RULES.
08300 C MXNC- MAXIMUM NUMBER OF MACHINES (ALL MACHINE GROUPS).
08400 C MXMN- MAXIMUM NUMBER OF MACHINES (ALL DEPARTMENTS).
08500 C MXORD- MAXIMUM NUMBER OF ORDERS IN SYSTEM.
08600 C MXPR0D- MAXIMUM NUMBER OF ITEMS.
08700 C
08800 C-----------------------------------------------
08900 C
09000 C MALT=993
09100 C MXCM=993
09200 C MXDPT=10
09300 C MXFIN=20
09400 C MXJOB=3
09500 C MXGRP=4
09600 C MXLJ=3
09700 C MXNC=3
09800 C MXMN=100
09900 C MXORD=100
10000 C MXPR0D=993
10100 C
10200 BVAL=10.0**10.0
10300 C IX=55498329
10400 C
10500 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
10600 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
10700 C
10800 C THIS SECTION CLEARS OUT ALL PRODUCT RELATED ARRAYS.
10900 C
11000 DO 11 I=1,10
11100 SSAVE(I)=0.0
11200 TLSTD(I)=0.0
11300 TABALD(I)=0.0
11400 QUEUE(I)=0.0
11500 11 CONTINUE
11600 DO 15 I=1,8
11700 AXLOAD(I)=0.0
11800 15 CONTINUE
11900 DO 21 K=1,5
12000 JFLAG(K)=0
21 CONTINUE
22100  KFLAG=0
22200  DO 24 XL=1,7
22300  IFLAG(XL)=0
22400  TTVAL(XL)=0.0
22500  24 CONTINUE
22600  DO 100 II=1,4
22700  DO 100 JJ=1,5
22800  DO 100 KK=1,7
23000  ASTAT1(I,XX,JJ,II)=0.0
23100  ASTAT1(2,XX,JJ,II)=0.0
23200  ASTAT1(3,XX,JJ,II)=0.0
23300  ASTAT1(4,XX,JJ,II)=3.0
23400  ASTAT1(5,XX,JJ,II)=-5.0
23500  100 CONTINUE
23600  DO 120 II=1,20
23700  DO 110 JJ=1,5
23800  OFUN(I,II,JJ)=0.0
23900  10 CONTINUE
24000  DO 110 CONTINUE
24100  OFUN(I,2,II)=0.0
24200  120 CONTINUE
24300  DO 160 II=1,MM.PROD
24400  GORC(I)=0.0
24500  ATNV(I)=0.0
24600  VALUE(I,1)=0.0
24700  VALUE(I,2)=0.0
24800  BLOG(I)=0.0
24900  OFUNC(I)=0.0
25000  BO(I)=0.0
25100  DO 133 JJ=1,5
25200  ISP(II,1,II)=0
25300  ISP(II,2,II)=0
25400  133 CONTINUE
25500  DO 135 JJ=1,5
25600  DO 134 LL=1,5
25700  OSTAT1(I,II,II,II)=0.0
25800  OSTAT1(I,II,II,II)=0.0
25900  134 CONTINUE
26000  DO 135 KK=1,5
26100  OSTAT2(KK,II,II,II)=0.0
26200  OSTAT2(KK,II,II,II)=0.0
26300  135 CONTINUE
26400  DO 140 JJ=1,5
26500  IQVSP(I,II,II)=0
26600  140 CONTINUE
26700  DO 150 JJ=1,5
26800  IQVSP(I,II,II)=0
26900  150 CONTINUE
27000  DO 150 CONTINUE
27100  DO 170 II=1,MM.3
27200  IQOUT(I)=0
27300  IQROUT(I,1)=0
27400  IQROUT(I,2)=0
27500  IQROUT(I,3)=0
27600  IQROUT(I,4)=0
27700  IQROUT(I,5)=0
27800  IQROUT(I,6)=0
27900  IQROUT(I,7)=0
28000  IQROUT(I,8)=0
18100    NBILL(I,J,3)=0
18200    NBILL(I,J,4)=0
18300    NBILL(I,J,5)=0
18400    NBILL(I,J,6)=0
18500    DO 170 JJ=1,5
18600    MRWTJ(I,J,J)=0
18700    CONTINUE
18800    C
18900    CCCC
19000    CCCCCCCC
19100    C
19200    C THIS SECTION CLEARS OUT ALL SHOP RELATED ARRAYS.
19300    C
19400    DO 230 II=1,11
19500    DO 190 JJ=1,11
19600    MDPT(JJ,II)=0
19700    CONTINUE
19800    DO 200 JJ=1,3
19900    DO 195 KK=1,3
20000    QDATA(KK,II)=0.0
20100    QDATA(KK,II,JI)=0.0
20200    QDATA(KK,II,JJ)=0.0
20300    QDATA(KK,II,JI,JJ)=0.0
20400    CONTINUE
20500    DO 2060 JJ=1,5
20600    DO 2070 KK=1,3
20700    QSTAT(JJ,1,III)=0.0
20800    QSTAT(JJ,2,III)=0.0
20900    CONTINUE
21000    DO 2110 JJ=1,12
21100    MCHGRP(JJ,II)=0
21200    CONTINUE
21300    DO 2140 JJ=1,11
21400    DO 2150 MM=1,11
21500    DO 2160 LL=1,5
21600    DO 2170 MM=1,3
21700    QSTAT(JJ,1,MM,LLL)=0.0
21800    QSTAT(JJ,2,MM,LLL)=0.0
21900    CONTINUE
22000    DO 2210 II=1,MMnum
22100    DO 2220 JJ=1,5
22200    MEN(JJ,II)=0
22300    CONTINUE
22400    MACH(JJ,II)=0
22500    CONTINUE
22600    DO 2270 JJ=1,4
22700    DO 2280 KK=1,3
22800    SMACH(JJ,II,KK)=0.0
22900    CONTINUE
23000    C
23100    CCCC
23200    CCCCCCCC
23300    C
23400    C THIS SECTION CLEARS OUT ALL ORDER RELATED ARRAYS.
23500    C
23600    DO 360 II=1,52
23700    NORD(II)=0
23800    NORD(II)=0
23900    PORD(II)=0
24000    RECT(II)=0
24100 SRECT(II)=0
24200 250 CONTINUE
24300 DO 300 II=1,4,10
24400  DO 270 JJ=1,3
24500  IRDJP(II, JJ)=0
24600 270 CONTINUE
24700  DO 290 JJ=1,9
24800  ORDER(II, JJ)=0.0
24900 290 CONTINUE
25000  DO 290 JJ=1,10
25100  INDEX(II, JJ)=0
25200 290 CONTINUE
25300  DO 300 JJ=1,15
25400  IRDRH(II, JJ)=0
25500 300 CONTINUE
25600  
25700  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I - REPORT PRINTED

I=7 - OUTPUT OPTIONAL WEEKLY OPERATION REPORTS STARTING WITH WEEK INPUTED FOR THIS VALUE.

I=8 - OUTPUT OPTIONAL WEEKLY OPERATION REPORTS END WITH WEEK INPUTED FOR THIS VALUE.

I=9 - OUTPUT OPTIONAL WEEKLY MAP EXPLOSIONS STARTING WITH WEEK INPUTED FOR THIS VALUE.

I=10 - OUTPUT OPTIONAL WEEK EXPLOSIONS ENDING WITH WEEK INPUTED FOR THIS VALUE.

I=11 - NOT USED.

I=12 - NOT USED.

I=13 - OUTPUT OPTIONAL PUNCH DEPENDENT VARIABLES

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THIS SECTION READS IN THE BASIC TIME PARAMETERS AND Initializes

ALL TIME RELATED VARIABLES.

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CLOCK - CURRENT TIME IN MINUTES.
DTIME - TIME OF NEXT END-OF-DAY.
IDAY - CURRENT DAY OF WEEK.
IRUN - CURRENT RUN NUMBER(0 = INITIALIZATION).
ISWEEK - CURRENT WEEK.
ISWEEK - NUMBER OF WEEKS IN EACH SIMULATION.
MCLEAR - NUMBER OF WEEKS USED TO INITIATE SYSTEM.
NDAY - CURRENT DAY(ABSOLUTE).
NRBB - NUMBER OF WEEKS IN MAP EXPLOSION.
NRUNS - NUMBER OF RUNS TO BE MADE.
STOP - END OF NEXT RUN(IN WEEKS).
STIME - TIME OF NEXT END-OF-PROCESSING EVENT.
SToday - NUMBER OF MINUTES IN A STANDARD DAY.

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READ(40,752) INUM

752 FORAT(1I)
DO 777 I=1,NUM
READ(40,753) AXLOAD(I)
773 FORAT(1O.2)
777 CONTINUE
READ(40,799) TOCODE
799 FORAT(13)
READ(40,300) WEEK,MCLEAR,NRBB,NRUNS,SToday
300 FORAT(4,2F10.3)
IF(PRINT.E1.1) WRITE(3,900) WEEK,MCLEAR,NRBB,NRUNS,SToday
900 FORMAT* SIMULATION TIME RELATED PARAMETERS"/
1 - NUMBER OF WEEKS PER SIMULATION RUN = "IS/;
2 - NUMBER OF WEEKS IN THE INITIALIZATION PERIOD = "IS/;
3 - NUMBER OF WEEKS IN MAP EXPLOSION = "IS/;
4 - NUMBER OF SIMULATION RUNS TO BE COMPLETED = "IS/;
5 - MINUTES IN STANDARD DAY = "FS-0,1)
CLOCK=0.0
PTIME=10.0**20.0
DTIME=0.0
LAEK=0
IDAY=0
NDAY=0
TCELE=0.0
IRUN=3

C STOP=NCLEAS+NLAEK

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C THIS SECTION READS IN THE BASIC SHOP STRUCTURE AND Initializes
C THE RELATED DATA STRUCTURES. VALIDITY CHECKS ARE MADE TO
C ENSURE THE CURRENT ARRAY SIZES ARE SUFFICIENT TO STORE THE
C REQUIRED DATA.

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C THIS SUBSECTION READS IN THE NUMBER OF DEPARTMENTS.

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C C

C READ(40,200) MDPT
C IF(INP1,2,1) WRITE(7,901) MDPT
C 901 FORMAT(1X,'TOTAL NUMBER OF DEPARTMENTS=',15)
C IF(MDPT.GT.1.AND. MDPT.LE.10) 200 310
C WRITE(7,902)
C 902 FORMAT(1X,'INPUT ERROR; NUMBER OF DEPARTMENTS EXCEEDS ',
C 1X,'MAXIMUM ALLOCABLE')
C STOP
C
C CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
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C C

C THIS SUBSECTION READS IN THE DEPARTMENTAL HEADER RECORD WHICH
C CONTAINS THE BASIC INFORMATION FOR EACH DEPARTMENT.

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C MDPT(1:J)*2 DEPARTMENTAL MASTER RECORD.

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C C

C SUBSCRIPT I*J DATA TYPE IDENTIFIER.
C I=1- NUMBER OF WORKERS CURRENTLY ASSIGNED TO THE
C DEPARTMENT.
C I=2- NUMBER OF CURRENTLY AVAILABLE WORKERS IN
C THE DEPARTMENT.
C I=3- POINTER TO FIRST AVAILABLE WORKER.
C I=4- NUMBER OF BUSY WORKERS IN THE DEPARTMENT.
C I=5- POINTER TO FIRST BUSY WORKER.
C I=6- NUMBER OF WORKERS CURRENTLY IN A DELAY STATE.
C I=7- POINTER TO FIRST "DELAYED" WORKER.
C I=8- NUMBER OF MACHINE GROUPS IN THE DEPARTMENT.
C I=9- POINTER TO FIRST MACHINE GROUP IN THE DEPARTMENT.
C I=10- LARGEST ASSIGNMENT RULE FOR THE DEPARTMENT. LARGEST
C WORKED REMAINED IN QUEUE, 2= LARGEST QUEUE MEASURED IN
C AMOUNT OF WORK, 3= QUEUE WITH HIGHEST PRIORITY JOB
C FIRST IN QUEUE.
I=11- JOB SEQUENCING RULE (1= SHORTEST PROCESSING TIME,
2= EARLIEST DUE DATE, 3= CRITICAL RATIO (STATIC)).
C SUBSCRIPT J= DEPARTMENT NUMBER.
C
310 MAN=1
320 KGRP=1
330 MGR=1
340 00 410 IDEPT=1,4027
350 READ(40,801) MDEPT(1, IDEPT), MDEPT(9, IDEPT),
360 MDEPT(10, IDEPT), MDEPT(11, IDEPT)
370 FORMAT(315)
801 MDEPT(2, IDEPT)=MDEPT(1, IDEPT)
380 MDEPT(3, IDEPT)=MAN
390 MDEPT(9, IDEPT)=KGRP
400 IF(IPRINT.EQ.1) WRITE(3, 903) IDEPT, MDEPT(1, IDEPT), MDEPT(3, IDEPT),
410 MDEPT(10, IDEPT), MDEPT(11, IDEPT)
420 903 FORMAT(/" *, '../\n", IDEPT, " TO:" , MDEPT(1, IDEPT), " IN:" , MDEPT(3, IDEPT),
430 MDEPT(10, IDEPT), " OF:" , MDEPT(11, IDEPT))
440 1* NUMBER OF AVAILABLE WORKERS =/", IS/, /
450 2* POINTER TO FIRST WORKER AVAILABLE =/", IS/, /
460 3* NUMBER OF MACHINE GROUPS =/", IS/, /
470 4* POINTER TO FIRST MACHINE GROUP =/", IS/, /
480 5* LABOR ASSIGNMENT RULE INDICATOR =/", IS/, /
490 6* JOB SEQUENCING RULE INDICATOR =/", IS/, /
CC CCCCCCCC
CC CCCCC
CC CCC
CC C
4500 C THIS SUBSECTION CHECKS THE AVAILABLE SPACE USED TO STORE
4600 C THE DEPARTMENTAL DATA. WHEN AN ARRAY OVERFLOW IS DETECTED
4700 C AN APPROPRIATE ERROR MESSAGE IS PRINTED AND EXECUTION STOPS.
4800 C
4550 C IF(MAN+MDEPT(1, IDEPT)-1.LE.MXMAN) GOTO 320
4560 WRITE(3, 904)
4570 904 FORMAT(" INPUT ERROR" ,Z TOTAL NUMBER OF WORKERS EXCEEDS",
4580 1* MAXIMUM ALLOWABLE.")
4590 STOP
4600 320 IF(KGRP+MDEPT(3, IDEPT)-1.LE.MXGRP) GOTO 330
4610 WRITE(3, 905)
4620 905 FORMAT(" INPUT ERROR" ,Z TOTAL NUMBER OF MACHINE GROUPS EXCEEDS",
4630 1* MAXIMUM ALLOWABLE.")
4640 STOP
4650 330 IF(MDEPT(10, IDEPT).GE.1. AND. MDEPT(5, IDEPT).LE.MXLAB)
4660 1 GOTO 340
4670 WRITE(3, 906)
4680 906 FORMAT(" INPUT ERROR" ,Z UNKNOWN LABOR ASSIGNMENT RULE")
4690 STOP
4700 340 IF(MDEPT(11, IDEPT).GE.1. AND. MDEPT(7, IDEPT).LE.MXJOB)
4710 1 GOTO 350
4720 WRITE(3, 907)
4730 907 FORMAT(" INPUT ERROR" ,Z UNKNOWN JOB SEQUENCING RULE")
4740 STOP
4750 C
4760 C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C C
4770 C THIS SUBSECTION READS IN A MACHINE GROUP RECORD FOR EACH MACHINE
4780 C GROUP IN THE CURRENT DEPARTMENT "IDEPT". THIS RECORD APPEARS AS
4790 C A COLUMN IN THE "MXGGR" ARRAY. EACH RECORD IS READ IN AND THE
APPROPRIATE DATA CHECKS MADE. THE MACHINE GROUP STATISTICS ARRAY
("QSTAT") IS ALSO INITIALIZED.

MCHRF(I,J)-2 MACHINE GROUP MASTER RECORD.

SUBSCRIPT I-Z DATA IDENTIFIER.
I=1- NUMBER OF MACHINES,
I=2- NUMBER OF AVAILABLE MACHINES,
I=3- POINTER TO FIRST AVAILABLE MACHINE IN "MACH" ARRAY,
I=4- NUMBER OF BUSY MACHINES,
I=5- POINTER TO FIRST BUSY MACHINE IN "MACH" ARRAY,
I=6- NUMBER OF MACHINES THAT ARE CURRENTLY IN A "DELAY"
STATUS (I.E., MACHINES THAT HAVE JOBS ASSIGNED TO THEM
BUT DOES NOT HAVE A WORKER AVAILABLE OR THE JOB HAS
NOT ARRIVED YET AT THE MACHINE GROUP).
I=7- POINTER TO FIRST "DELAYED" MACHINE IN THE "MACH" ARRAY.
I=8- NOT USED
I=9- NOT USED
I=10- POINTER TO FIRST ORDER IN THE MACHINE GROUP QUEUE.

QSTAT(I,J,X,L)-2 OBSERVATIONAL MACHINE GROUP COLLECTORS.

SUBSCRIPT I-Z DATA TYPE IDENTIFIER.
I=1- SUM OF THE OBSERVATIONS,
I=2- SUM OF THE OBSERVATIONS SQUARED,
I=3- NUMBER OF OBSERVATIONS,
I=4- MINIMUM VALUE OF OBSERVATIONS,
I=5- MAXIMUM VALUE OF OBSERVATIONS.

SUBSCRIPT J-Z OBSERVATION PERIOD IDENTIFIER.
J=1- CURRENT RUN,
J=2- ALL RUNS SINCE "MCLEAR".

SUBSCRIPT K-Z COLLECTOR IDENTIFIER.
K=1- HOURS BY ORDER,
K=2- HOURS OF WORK ARRIVING BY WEEK,
K=3- HOURS OF WORK COMPLETED BY WEEK,
K=4- SUM OF HOURS COMPLETED BY WEEK AND HOURS
OF WORK REMAINING IN QUEUE AT END OF WEEK,
K=5- SETUP TIME/JOB IN HOURS,
K=6- RUN TIME/JOB IN HOURS,
K=7- TOTAL TIME/JOB IN HOURS,
K=8- ABSOLUTE WEEKLY CHANGE IN THE TOTAL LOAD.

SUBSCRIPT L-Z MACHINE GROUP NUMBER.

QSTAT(I,J,X,L)-2 TIME-PERSISTENT MACHINE GROUP COLLECTORS.

SUBSCRIPT I-Z DATA TYPE IDENTIFIER.
I=1- CURRENT VALUE OF THE VALUE BEING COLLECTED,
I=2- INTEGRAL AMOUNT (AREA UNDER CURVE) UP TO
TIME OF LAST UPDATE,
I=3- CUMULATIVE AREA SQUARED,
I=4- TIME OF LAST UPDATE.
<table>
<thead>
<tr>
<th>Line</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>54100</td>
<td>C I=5- MINIMUM VALUE DURING OBSERVATION PERIOD.</td>
</tr>
<tr>
<td>54200</td>
<td>C I=6- MAXIMUM VALUE DURING OBSERVATION PERIOD.</td>
</tr>
<tr>
<td>54300</td>
<td>C SUBSCRIPT J-Z OBSERVATION PERIOD IDENTIFIER.</td>
</tr>
<tr>
<td>54400</td>
<td>C J=1- CURRENT RUN.</td>
</tr>
<tr>
<td>54600</td>
<td>C J=2- ALL RUNS SINCE &quot;CLEAR&quot;.</td>
</tr>
<tr>
<td>54700</td>
<td>C SUBSCRIPT K-Z COLLECTOR IDENTIFIER.</td>
</tr>
<tr>
<td>54800</td>
<td>C K=1- NUMBER OF ORDERS IN QUEUE.</td>
</tr>
<tr>
<td>54900</td>
<td>C K=2- NUMBER OF HOURS IN QUEUE.</td>
</tr>
<tr>
<td>55000</td>
<td>C K=3- NOT USED.</td>
</tr>
<tr>
<td>55200</td>
<td>C SUBSCRIPT L-Z MACHINE GROUP NUMBER.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>55600</td>
<td>C MSTAT(I,J,K)^Z ACCUMULATOR ARRAY USED TO RETAIN THE NUMBER OF JOBS IN THE BEGINNING QUEUE, NUMBER OF ARRIVALS, AND NUMBER OF COMPLETIONS.</td>
</tr>
<tr>
<td>55700</td>
<td>C SUBSCRIPT I-Z DATA TYPE IDENTIFIER</td>
</tr>
<tr>
<td>55800</td>
<td>C I=1- NUMBER OF JOBS IN BEGINNING QUEUE.</td>
</tr>
<tr>
<td>55900</td>
<td>C I=2- NUMBER OF JOBS ARRIVING DURING TIME PERIOD.</td>
</tr>
<tr>
<td>56000</td>
<td>C I=3- NUMBER OF JOBS COMPLETED DURING TIME PERIOD.</td>
</tr>
<tr>
<td>56100</td>
<td>C SUBSCRIPT J-Z MACHINE GROUP NUMBER.</td>
</tr>
<tr>
<td>56200</td>
<td>C SUBSCRIPT K-Z OBSERVATION PERIOD IDENTIFIER.</td>
</tr>
<tr>
<td>56300</td>
<td>C K=1- CURRENT WEEK.</td>
</tr>
<tr>
<td>56400</td>
<td>C K=2- CURRENT RUN.</td>
</tr>
<tr>
<td>56500</td>
<td>C K=3- ALL RUNS SINCE &quot;CLEAR&quot;.</td>
</tr>
<tr>
<td>56600</td>
<td>C SUBSCRIPT L-Z MACHINE GROUP NUMBER.</td>
</tr>
<tr>
<td>56700</td>
<td>C SUBSCRIPT M-J-Z ACCUMULATOR ARRAY CONTAINING THE JOB RELATED DATA.</td>
</tr>
<tr>
<td>56800</td>
<td>C SUBSCRIPT I-Z TYPE TYPE IDENTIFIER</td>
</tr>
<tr>
<td>56900</td>
<td>C I=1- TOTAL SETUP TIME OF JOBS WAITING IN QUEUE AT BEGINNING OF CURRENT PERIOD.</td>
</tr>
<tr>
<td>57000</td>
<td>C I=2- TOTAL RUN TIME OF JOBS WAITING IN QUEUE AT BEGINNING OF CURRENT PERIOD.</td>
</tr>
<tr>
<td>57100</td>
<td>C I=3- TOTAL SETUP TIME OF JOBS ARRIVING DURING THE CURRENT RUN PERIOD.</td>
</tr>
<tr>
<td>57200</td>
<td>C I=4- TOTAL RUN TIME OF JOBS ARRIVING DURING THE CURRENT TIME PERIOD.</td>
</tr>
<tr>
<td>57300</td>
<td>C SUBSCRIPT J-Z MACHINE GROUP NUMBER.</td>
</tr>
<tr>
<td>57400</td>
<td>C SUBSCRIPT K-Z OBSERVATION PERIOD IDENTIFIER.</td>
</tr>
<tr>
<td>57500</td>
<td>C K=1- CURRENT WEEK.</td>
</tr>
<tr>
<td>57600</td>
<td>C K=2- CURRENT RUN.</td>
</tr>
<tr>
<td>57700</td>
<td>C K=3- ALL RUNS SINCE &quot;CLEAR&quot;.</td>
</tr>
<tr>
<td>57800</td>
<td>C QBATA(I,J,K)^Z QUEUE RELATED DATA FOR MACHINE GROUPS.</td>
</tr>
<tr>
<td>57900</td>
<td>C SUBSCRIPT I-Z DATA TYPE IDENTIFIER</td>
</tr>
<tr>
<td>58000</td>
<td>C I=1- TOTAL SETUP TIME OF JOBS CURRENTLY IN QUEUE.</td>
</tr>
<tr>
<td>58100</td>
<td>C I=2- TOTAL RUN TIME OF JOBS CURRENTLY IN QUEUE.</td>
</tr>
</tbody>
</table>
I=3 - TIME OF LAST JOB ASSIGNMENT.

SUBSCRIPT J=Z MACHINE GROUP NUMBER

------------------------------------------------------------------------

VAL-CHARGE(1,1)=VAL;
DO 380 I=1,VAL
380 READ(40,801) MCHGRP(1,1),GRP.
MCHGRP(2,1)=CHGRP(1,1),GRP.
MCHGRP(3,1)=CH
DO 351 KKK=1,3
DO 351 LLL=1,2
QSTAT(4,LLL,KKK,GRP)=3VAL
QSTAT(3,LLL,KKK,GRP)=3VAL
CONTINUE
351 IF(IPRINT.EQ.1) WRITE(3,903) IL,MCHGRP(1,1),GRP.,MCHGRP(3,1),GRP.
FORMAT(* MACHINE GROUP = "IL, GRP.")
16X,"NUMBER OF MACHINES = ",I5,
16X,"POINTER TO FIRST AVAILABLE MACHINE = ",I5,
MCHGRP(1,1),GRP.
WRITE(3,903) FORMAT(* INPUT ERROR: Z TOTAL NUMBER OF MACHINES EXCEEDS ",MACH(1,J)Z INDIVIDUAL MACHINE RECORD.
FOR ALL MACHINES IN CURRENT MACHINE GROUP.
SUBSCRIPT J=Z INDIVIDUAL MACHINE NUMBER (USED FOR REFERENCE).

SUBSCRIPT I=Z DATA TYPE IDENTIFIER.
I=1 - STATUS OF MACHINE (0 = UNASSIGNED, 1 = BUSY, 2 = DELAY STATUS).
I=2 - POINTER TO ORDER CURRENTLY BEING WORKED ON.
I=3 - POINTER TO WORKER CURRENTLY ASSIGNED TO MACHINE.
I=4 - POINTER TO PRIOR MACHINE IN LIST.
I=5 - POINTER TO NEXT MACHINE IN LIST.

SUBSCRIPT I=Z DATA TYPE IDENTIFIER.
I=1 - TOTAL STANDARD SETUP TIME.
I=2 - TOTAL ACTUAL SETUP TIME.
I=3 - TOTAL RUN TIME (STANDARD).
I=4 - TOTAL RUN TIME (ACTUAL).
SUBSCRIPT J=Z MACHINE NUMBER.
SUBSCRIPT K=Z OBSERVATION PERIOD IDENTIFIER.
66100 C K = 1 - CURRENT WEEK.
66200 C K = 2 - CURRENT RUN.
66300 C K = 3 - ALL RUNS SINCE "HOLEAR".
66400 C
66500 C---------------------------------------------------------------
66600 C
66700 360 MVAL = MCHSRP(I, MGRP)
66800 C MCH = MCH
66900 DO 370 J = 1, MVAL
67000 MACH(4, MCH) = MCH + 1
67100 MACH(5, MCH) = MCH + 1
67200 MCH = MCH + 1
67300 CONTINUE
67400 MACH(4, LMCH) = 0
67500 MACH(5, LMCH) = 0
67600 MGRP = MGRP + 1
67700 380 CONTINUE
67800 C
67900 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
68000 C
68100 C THIS SUBSECTION READS IN THE PRODUCTIVITIES OF THE
68200 C DEPARTMENT'S WORKERS. THE PRODUCTIVITY IS AN INDEX
68300 C VALUE BETWEEN 50 AND 150. THE VALUES REPRESENT THE
68400 C PERCENT OF STANDARD TIME REQUIRED BY THE WORKER TO
68500 C COMPLETE A JOB.
68600 C
68700 C
68800 C
68900 C MEN(I, J) = Z INDIVIDUAL WORKER RECORD.
69000 C
69100 C SUBSCRIPT I = Z DATA TYPE IDENTIFIER.
69200 C I = 1 - PRODUCTIVITY INDEX FOR WORKER.
69300 C I = 2 - POINTER TO ORDER CURRENTLY BEING WORKED ON.
69400 C I = 3 - POINTER TO CURRENT MACHINE BEING USED.
69500 C I = 4 - POINTER TO PRIOR WORKER IN LIST.
69600 C I = 5 - POINTER TO NEXT WORKER IN LIST.
69700 C
69800 C SUBSCRIPT J = Z INDIVIDUAL WORKER NUMBER (USED FOR REFERENCE).
69900 C
70000 C---------------------------------------------------------------
70100 C
70200 MVAL = MCHSRP(I, IDEPT) * MAN - 1
70300 READ(40, 901) (MEN(I, I), I = MAN, MVAL)
70400 IF (IPEPT .EQ. 1) WRITE(3, 910) (MEN(I, I), I = MAN, MVAL)
70500 910 FORMAT (' DEPARTMENT LABOR SUMMARY Z',//,
70600 15(/, 6X, 30(I3, 2X)),//)
70700 DO 400 II = MAN, MVAL
70800 IF (MEN(I, I) .GE. 50. AND. MEN(I, I) .LE. 150) GOTO 390
70900 WRITE(3, 911)
71000 911 FORMAT (' INPUT ERROR Z PRODUCTIVITY OUTSIDE ALLOWABLE LIMITS')
71100 STOP
71200 390 MEN(4, II) = II - 1
71300 MEN(5, II) = II + 1
71400 400 CONTINUE
71500 MEN(4, MAN) = 0
71600 MEN(5, MVAL) = 0
71700 MAN = MVAL + 1
71800 410 CONTINUE
71900 420 MGRP = MGRP
72000 DO 415 XXX = 1, 1
DO 415 LLL=1,3
QSTATE(4,XX,LLL,NGRP)=3*VAL
QSTATE(3,XX,LLL,NGRP)=-3*VAL
415 CONTINUE
C
C THIS SECTION READS IN THE PRODUCT STRUCTURE AND INITIALIZES THE
C RELATED DATA STRUCTURES. VALIDITY CHECKS ARE MADE TO INSURE
C THE CURRENT ARRAY SIZES ARE ADEQUATE TO STORE THE REQUIRED DATA
C AND THE DATA IS CONSISTENT WITH THE SHOP STRUCTURE SPECIFIED.
C
C------------------------------------------------------------------------
C
C MPROD- TOTAL NUMBER OF INVENTORIZED ITEMS
C NFIN- NUMBER OF FINISHED ITEMS
C NPUR- NUMBER OF PURCHASED ITEMS (I.E. RAW MATERIALS)
C NOEM- NUMBER OF INDEPENDENT DEMAND ITEMS (INCLUDES END ITEMS)
C CARRY- COST OF CARRYING INVENTORY AS A PERCENTAGE
C INVF- COST OF INVENTORY VALUE (PER YEAR)
C
C------------------------------------------------------------------------
C
C READ(46,305) MP, NFIN, NPUR, NOEM, CARRY
C 305 FORMAT(4(3F10.0))
C 306 IF(IRUN.EQ.1) WRITE(3,912) MP, NFIN, NPUR, NOEM, CARRY
C 912 FORMAT(' PRODUCT STRUCTURE PARAMETERS'"
C 1* NUMBER OF ITEMS =",I5,
C 2* NUMBER OF FINISHED ITEMS =",I5,
C 3* NUMBER OF PURCHASED ITEMS =",I5,
C 4* NUMBER OF INDEPENDENT DEMAND ITEMS =",I5,
C 5* COST OF INVENTORY VALUE =",5.3,
C IF(NPROD<ST.0.AND.NPROD-MPROD) GO TO 420
C 420 WRITE(3,913)
C 913 FORMAT(' INPUT ERROR: IMPROPER NUMBER OF ITEMS SPECIFIED')
C STOP
C 430 IF(NFIN<ST.0.AND.NFIN-MFIN) GO TO 430
C 914 FORMAT(' INPUT ERROR: IMPROPER NUMBER OF FINISHED ITEMS ')
C STOP
C 440 IF(NPUR<ST.0.AND.NPUR-MPUR) GO TO 440
C 915 FORMAT(' INPUT ERROR: IMPROPER NUMBER OF PURCHASED ITEMS ')
C STOP
C 450 IF(NOEM<ST.0.AND.NOEM-NOEM) GO TO 450
C 916 FORMAT(' INPUT ERROR: IMPROPER NUMBER OF INDEPENDENT DEMAND ')
C STOP
C
INVRD(I,J) 2 INVENTORY MASTER RECORD (FULL WORD).

SUBSCRIPT I-Z ITEM NUMBER.

J=1- UNALLOCATED INVENTORY.
J=2- ALLOCATED INVENTORY.
J=3- FIXED ORDER QUANTITY (USED WITH LOT SIZE RULE #2).
J=4- UN-ORDER QUANTITY.
J=5- SAFETY STOCK LEVEL.
J=6- MINIMUM ORDER RELEASE SIZE.
J=7- NOT USED.

INVRDHI(I,J) 2 INVENTORY MASTER RECORD (HALF WORD INTEGER)

SUBSCRIPT I-Z ITEM NUMBER.

J=1- LEAD TIME (IN WEEKS).
J=2- LOT SIZE RULE (1- LOT FOR Lot FOR LOT, 2- FIXED ORDER QUANTITY).
J=3- NUMBER OF DIFFERENT COMPONENTS IN "RELEASE" BILL OF MATERIALS.
J=4- POINTER TO FIRST ENTRY IN "RELEASE" BILL OF MATERIALS.
J=5- NUMBER OF PARENTS IN "MRP" BILL OF MATERIALS.
J=6- POINTER TO FIRST ENTRY IN "MRP" BILL OF MATERIALS.
J=7- NUMBER OF OPERATIONS.
J=8- POINTER TO FIRST ENTRY IN OPERATIVITY LIST.
J=9- NUMBER OF ORDERS IN PROCESS.
J=10- POINTER TO FIRST ORDER IN PROCESS.
J=11- BACKLOG CORRECTION.

VALVE(I,J) 2 INVENTORY COST RECORD.

SUBSCRIPT I-Z ITEM NUMBER.

J=1- COST PER UNIT (IN DOLLARS).
J=2- COST PER ORDER (IN DOLLARS).

OSTAT(I,J,X,L) 2 OBSERVATIONAL ITEM/ORDER COLLECTIONS.

SUBSCRIPT I-Z DATA TYPE IDENTIFIERS.

I=1- SUM OF THE OBSERVATIONS.
I=2- SUM OF THE OBSERVATIONS SQUARED.
I=3- NUMBER OF OBSERVATIONS.
I=4- MINIMUM VALUE OF OBSERVATIONS.
I=5- MAXIMUM VALUE OF OBSERVATIONS.

SUBSCRIPT J-Z OBSERVATION PERIOD IDENTIFIER.

J=1- CURRENT RUN.
J=2- ALL RUNS SINCE "CLEAR".

SUBSCRIPT X-Z COLLECTOR IDENTIFIER.

X=1- ACTUAL TIME (FLOATABLE) IN STANDARD DAYS.
<table>
<thead>
<tr>
<th>Line</th>
<th>Description</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>34100</td>
<td>$K^2$: wait time in standard days.</td>
<td></td>
</tr>
<tr>
<td>34200</td>
<td>$K^3$: order lateness in standard days.</td>
<td></td>
</tr>
<tr>
<td>34300</td>
<td>$K^4$: order tardiness in standard days.</td>
<td></td>
</tr>
<tr>
<td>34400</td>
<td>$K^5$: order release delay in standard days.</td>
<td></td>
</tr>
<tr>
<td>34500</td>
<td>$K^6$: actual size of order release.</td>
<td></td>
</tr>
<tr>
<td>34600</td>
<td>$K^7$: planned size of order release.</td>
<td></td>
</tr>
<tr>
<td>34700</td>
<td>$K^8$: actual demand over lead time.</td>
<td></td>
</tr>
<tr>
<td>34800</td>
<td>$K^9$: not used.</td>
<td></td>
</tr>
<tr>
<td>34900</td>
<td>SUBSCRIPT L-Z ITEM NUMBER.</td>
<td></td>
</tr>
<tr>
<td>35000</td>
<td>SUBSCRIPT L-Z ITEM NUMBER.</td>
<td></td>
</tr>
<tr>
<td>35100</td>
<td>SUBSCRIPT L-Z ITEM NUMBER.</td>
<td></td>
</tr>
<tr>
<td>35200</td>
<td>SUBSCRIPT L-Z ITEM NUMBER.</td>
<td></td>
</tr>
<tr>
<td>35300</td>
<td>SUBSCRIPT L-Z ITEM NUMBER.</td>
<td></td>
</tr>
<tr>
<td>35400</td>
<td>SUBSCRIPT L-Z ITEM NUMBER.</td>
<td></td>
</tr>
<tr>
<td>35500</td>
<td>SUBSCRIPT L-Z ITEM NUMBER.</td>
<td></td>
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<td>40000</td>
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90100  ICO=1
90200  ISILL=1
90300  DD 590 IPROD=1,IPROD
90400  READ(40,802) INVRDF(IPROD,1),INVRDF(IPROD,3),INVRDF(IPROD,5),
90500  INVRDF(IPROD,6),INVRDF(IPROD,1),INVRDF(IPROD,2),INVRDF(IPROD,7),
90600  2VALUE(IPROD,1),VALUE(IPROD,2)
90700  302 FORMAT(3X,17,J110,35,2F10.0)
90800  IF(9RTN,50.1) WRITE(3,917) IPROD,INVRDF(IPROD,1),INVRDF(IPROD,3),
90900  INVRDF(IPROD,5),INVRDF(IPROD,2),INVRDF(IPROD,1),INVRDF(IPROD,2),
91000  2VALUE(IPROD,1),VALUE(IPROD,2),INVRDF(IPROD,7)
91100  917 FORMAT(/" PRODUCT "/,13,"Z",/,
91200  1" STARTING INVENTORY "/,13,"/ FIXED ORDER QUANTITY "/,13,"/,
91300  2" SAFETY STOCK "/,13,"/ MINIMUM RELEASE SIZE "/,13,"/,
91400  3" LEAD TIME (IN WEEKS) "/,13,"/ LOT SIZE RULE "/,13,"/,
91500  3" COST PER UNIT "/,13,"/ SETUP COST "/,
91600  4F3.2/" NUMBER OF OPERATIONS "/,13)
91700  IF(INVRDF(IPROD,2).GE.1.AND.INVRDF(IPROD,2).LE.4XLOT) GOTO 460
91800  WRITE(3,918)
91900  918 FORMAT(" INPUT ERROR: UNKNOWN LOT SIZE RULE SPECIFIED")
92000  STOP
92100  C
92200  C INITIALIZE ALL NON-ZERO TIME-RELATED COLLECTORS.
92300  C
92400  460 A(1)=INVRDF(IPROD,1)
92500  A(2)=A(1)*VALUE(IPROD,1)
92600  DO 465 II=1,2
92700  DO 464 JJ=1,9
92800  C OSTATE(5,II,JJ,IPROD)=A(N)
92900  C OSTATE(5,II,JJ,IPROD)=A(N)
93000  454 CONTINUE
93100  DO 465 JJ=1,2
93200  C OSTATE(1,II,JJ,IPROD)=A(JJ)
93300  C OSTATE(1,II,JJ,IPROD)=A(JJ)
93400  C OSTATE(1,II,JJ,IPROD)=A(JJ)
93500  465 CONTINUE
93600  C INVRDF(IPROD,3)=IP
93700  C
93800  C
cCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
93900  C
94000  C THIS SUBSECTION READS IN THE ROUTING AND BILL OF MATERIALS FOR
94100  C ALL MANUFACTURED ITEMS (I.E. NOT PURCHASED). CHECKS ARE MADE
94200  C TO ENSURE THAT ALL ROUTING INFORMATION (I.E. DEPARTMENT NUMBERS
94300  C AND MACHINE GROUP NUMBERS ARE COMPATIBLE WITH THE SHOP STRUCTURE.)
94400  C
94500  C
94600  C
94700  C MROUT(I,J)-Z OPERATION MASTER RECORD.
94800  C
94900  C
95000  C
95100  C
95200  C
95300  C
95400  C
95500  C
95600  C
95700  C
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98500  C
98600  C
98700  C
98800  C
98900  C
99000  C
99100  C
IF(CHOP.EQ.0) GO TO 590
ICH=J
DO 550 JJ=1,CHOP
REJO(40,901) IROUT(IOP,1), IROUT(IOP,2), IROUT(IOP,4)
IF(IROUT(IOP,3).GT.IALT)
IROUT(IOP,3)=IALT
IF(CHOP(IOP,4).GE.0) IROUT(IOP,5)=ICOM
IF(IROUT(IOP,5).LE.0)
READ(3,919) JJ,(IROUT(IOP,XX),XX=1,5)
IF(CHOP(IOP,4).GT.1)
IF(CHOP(IOP,4).LE.40)
WRITE(3,919) JJ,(IROUT(IOP,XX),XX=1,5)
ELSE IF(CHOP(IOP,4).GT.40)
WRITE(3,919) JJ,(IROUT(IOP,XX),XX=1,5)
ELSE WRITE(3,920)
919 FORMAT(31,1X, "OPERATION ", I2, " IN DEPARTMENT ", I2,
1X, "NUMBER OF ALTERNATIVES ", I4, 1X,
24X, "LENGTH OF FIRST ALTERNATIVE ", I4, 1X,
34X, "NUMBER OF COMPONENTS ", I4, 1X,
44X, "LENGTH OF FIRST COMPONENT ", I4, 1X,
IF(MROUT(IOP,1).LT.1 .AND. MROUT(IOP,1).GE.100000)
GOTO 470
919 FORMAT(31,1X, "INPUT ERROR Z UNKNOWN DEPARTMENT NUMBER SPECIFIED ",
1X, "IN ROUTING")
STOP
920 FORMAT(31,1X, "INPUT ERROR Z TOTAL ALTERNATIVES EXCEEDS MAXIMUM ALLOWABLE")
STOP
921 FORMAT(31,1X, "INPUT ERROR Z TOTAL NUMBER OF COMPONENTS EXCEEDS MAXIMUM ALLOWABLE")
STOP
97800 480 IF(CHOP(IOP,4).GT.1 .AND. MROUT(IOP,4).LE.40)
98000 WRITE(3,930)
98000 STOP
98100 490 IF(CHOP(IOP,4).GT.1 .AND. MROUT(IOP,4).GT.40)
98300 STOP
98400 490 IF(CHOP(IOP,4).GT.1 .AND. MROUT(IOP,4).GT.40)
98500 WRITE(3,932)
98500 STOP
C
99000 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
99100 C THIS SUBSECTION READS IN THE ALTERNATIVE OPERATION(S)
99300 C ASSOCIATED WITH THE CURRENT OPERATION.
99400 C
99500 C-------------------------------------------------------------------------------
99600 C IROUT(I) = MACHINE GROUP NUMBER OF ALTERNATIVE OPERATION.
99700 C
99900 C SUBSCRIPT I = RECORD IDENTIFIER(LOCATION).
C ORM Twitch ALTERNATIVE PROCESSING REQUIREMENTS RECORD.
C ORM Twitch ALTERNATIVE PROCESSING REQUIREMENTS RECORD.
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C ORM Twitch ALTERNATIVE PROCESSING REQUIREMENTS RECORD.
06100  I" COMPONENT IN ROUTING")
06200  STOP
06300  S20  ICOM=ICOM+1
06400  S30  CONTINUE
06500  S40  IQP=IQP+1
06600  S50  CONTINUE
06700  C
06800  CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
06900  C
07000  C  THIS SUBSEATION Restructures THE COMPONENTS OF THE CURRENT ITEM
07100  C  INTO A FORM USED BY THE "DELIVER" SUBROUTINE. THIS IS REFERRED
07200  C  TO AS THE "RELEASE" BILL OF MATERIALS.
07300  C
07400  C
07500  C
07600  C  NBILL(I,J)=2 "RELEASE" BILL OF MATERIALS ARRAY AND COMPONENT.
07700  C  SHORTAGE COLLECTOR.
07800  C
07900  C  SUBSCRIPT, I="" COMPONENT IDENTIFIER
08000  C
08100  C  SUBSCRIPT J=", DATA TYPE IDENTIFIER.
08200  C
08300  C  J=1- COMPONENT IDENTIFIER
08400  C  J=2- USAGE INDICATOR
08500  C  J=3- SHORTAGE INCIDENT COUNTER
08600  C  J=4- QUANTITY AVAILABLE LESS THAN MINIMUM RELEASE QUANTITY.
08600  C
08700  C
08800  C
08900  IF(IVC7.EQ.0) G0T 590
09000  DO 570 II=1,ICNT
09100  IF(ISAVE(I1,1).EQ.0) G0T 570
09200  ITEMP=ISAVE(I1,1)
09300  IVL=II+1
09400  DO 560 JJ=IVL,ICNT
09450  IF(ITEMP.EQ.ISAVE(JJ,1)) G0T 560
09460  C
09470  ISAVE(JJ,1)=0
09480  ISAVE(JJ,2)=ISAVE(I1,2)+ISAVE(JJ,2)
09490  560 CONTINUE
09500  570 CONTINUE
10000  NCNT=0
10100  INVRDOX(PROD,4)=IBILL
10200  DO 550 II=1,ICNT
10300  IF(ISAVE(I1,1).EQ.0) G0T 580
10400  NBILL(IBILL,1)=ISAVE(I1,1)
10500  NBILL(IBILL,2)=ISAVE(I1,2)
10600  IBILL=IBILL+1
10700  NCNT=NCNT+1
10800  580 CONTINUE
10900  INVRDOX(PROD,3)=VCNT
11000  590 CONTINUE
11100  C
11200  CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
11300  C
11400  C
11500  C  THIS SECTION Restructures THE "RELEASE" BILL OF MATERIALS
11600  C  TO FORM THE "VRP" BILL OF MATERIALS. THIS BILL OF MATERIALS
11700  C  IS ORGANIZED ON A PARENT BASIS.
11800  C
11900  C
12000  C
HMILL(I,J)*Z "MRP" BILL OF MATERIALS ARRAY.

SUBSCRIPT I*Z RECORD IDENTIFIER(LOCATION).

SUBSCRIPT J*Z DATA TYPE IDENTIFIER.

J=1- ITEM NUMBER OF PARENT.

J=2- QUANTITY RELATIONSHIP.

MV=NFV+1
IBILL=1
DO 630 IPROD=MTAL,IPROD
MPAR=0
INVPH(IPROD,3)=IBILL
IND=1
IPROD=IPROD
IF(IPROD.GT.IPPOD) IPPOD=IPROD
DO 629 II=1,IPROD
NC=INVPH(II,3)
IND=INVADH(II,4)
DO 510 JJ=1,NC
IND=II,NC
MBILL(II,1)=II
IF(MBILL(IND,1).NE.IPPOD) GOTO 600
MBILL(II,2)=MBILL(IND,2)
IBILL=IBILL+1
IPAR=IPAR+1
GOTO 600
IND=IND+1
CONTINUE
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INVPH(IPROD,3)=IPAR
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CON...
C J=3- MAXIMUM MAGNITUDE OF SEASONAL VARIATION.
18200 C J=4 - MAXIMUM LEVEL OF FORECAST ERROR AS PERCENTAGE
18300 C OF BASE LEVEL OF DEMAND.

18600 C
18700 C IF(IPRINT.EQ.1) WRITE(3,127)
18800 C 927 FORMAT *(IDF(N,II,JJ),JJ=1,3), (DFUN(II,JJ),JJ=1,4)
18900 C 307 FORMAT *(IPRINT.EQ.1) WRITE(3,928) (IDF(N,II,JJ),JJ=1,3), (DFUN(II,JJ),
19000 C JJ=1,4)
19100 C 928 FORMAT *(3X,II,15),(5X,2F10.3)
19200 C INVROH(IDF(N,II,1),5)=INVRH(IDF(N,II,1),5)
19300 C 640 CONTINUE

19900 C CALCULATE REORDER POINT.
20000 C
20100 C DO 641 II=1,100
20200 C MDEH(II)=N
20300 C
20400 C 641 CONTINUE
20500 C DO 642 II=1,100
20600 C IPROD=IDF(N,II,1)
20700 C MDEH(IPROD)=DFUN(II,1)
20800 C 642 CONTINUE
20900 C DO 643 IPROD=1,NPROD
21000 C IF(INVRH(IPROD,1).LT.0) GOTO 543
21100 C IPR=INVRH(IPROD,4)
21200 C NV=INVRH(IPROD,3)
21300 C DO 643 II=1,NVAL
21400 C JPR=VILL(IPR,1)
21500 C MDEH(JPR)=MDEH(IPR)+3*VILL(IPR,2)*MDEH(IPR)
21600 C IPR=IPR+1
21700 C 643 CONTINUE
21800 C DO 644 IPROD=1,NPROD
21900 C INVROH(IPROD,7)=MDEH(IPROD)*INVROH(IPROD,1)
22000 C 644 CONTINUE
22100 C IF(IPRINT.EQ.1) WRITE(3,3600) (INVROH(JJ,7),JJ=1,NPROD)
22200 C 3600 FORMAT *(3X,II,15), (1X,10I10)
22300 C
22400 C THIS SECTION INITIALIZES THE ORDER INDEXES AND POINTERS.
22500 C
22600 C
22700 C DO 650 II=1,NPROD
22800 C INDEX(II,1)=II-1
22900 C INDEX(II,2)=II+1
23000 C 650 CONTINUE
23100 C INDEX(I,1)=0
23200 C INDEX(I,2)=0
23300 C DO 660 II=1,NPROD
23400 C INDEX(I,3)=I
23500 C 660 CONTINUE
23600 C
23700 C 660 CONTINUE
23800 C MVAL=1
23900 C MVERT=0
24000 C MPROD=0
MRMARR = 0

24400 C
244300 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
244900 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
24500 C
245600 C THIS SECTION CALCULATES THE INITIAL VALUES FOR THE AGGREGATE
24700 C INVENTORIES.
24800 C
249000 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
25000 C ASTAT(1, I, J, K) = Z AGGREGATE ITEM/ORDER COLLECTORS.
25100 C
25200 C SUBSCRIPT I-Z DATA IDENTIFIERS.
25300 C I=1- SUM OF THE OBSERVATIONS.
25400 C I=2- SUM OF THE OBSERVATIONS SQUARED.
25500 C I=3- NUMBER OF OBSERVATIONS.
25600 C I=4- MINIMUM VALUE OF OBSERVATIONS.
25700 C I=5- MAXIMUM VALUE OF OBSERVATIONS.
25800 C
25900 C SUBSCRIPT J-Z OBSERVATION PERIOD IDENTIFIER.
26000 C J=1- CURRENT RUN.
26100 C J=2- ALL RUNS SINCE "NCLEAR".
26200 C
26300 C SUBSCRIPT K-Z COLLECTOR IDENTIFIER.
26400 C K=1- FLOWTIME(IN STANDARD DAYS).
26500 C K=2- WAITTIME(IN STANDARD DAYS).
26600 C K=3- LATENESS(IN STANDARD DAYS).
26700 C K=4- TARDINESS(IN STANDARD DAYS).
26800 C K=5- RELEASE DELAY(IN STANDARD DAYS).
26900 C
27000 C SUBSCRIPT L-Z AGGREGATE INVENTORY CLASS.
27100 C L=1- FINISHED ITEMS.
27200 C L=2- INTERMEDIATE MANUFACTURED ITEMS.
27300 C L=3- PURCHASED ITEMS.
27400 C L=4- OVERALL CLASS.
27500 C
27600 C
27700 C
27800 C ASTAT(1, I, J, X) = Z AGGREGATE INVENTORY(IN DOLLARS) COLLECTORS.
27900 C
28000 C SUBSCRIPT I-Z DATA IDENTIFIERS.
28100 C I=1- CURRENT VALUE OF THE VALUE BEING COLLECTED.
28200 C I=2- CUMULATIVE AMOUNT(AREA UNDER CURVE) UP TO
28300 C TIME OF LAST UPDATE.
28400 C I=3- CUMULATIVE AREA SQUARED.
28500 C I=4- TIME OF LAST UPDATE.
28600 C I=5- MINIMUM VALUE DURING OBSERVATION PERIOD.
28700 C I=5- MAXIMUM VALUE DURING OBSERVATION PERIOD.
28800 C
28900 C SUBSCRIPT J-Z OBSERVATION PERIOD IDENTIFIER.
29000 C J=1- CURRENT RUN.
29100 C J=2- ALL RUNS SINCE "NCLEAR".
29200 C
29300 C SUBSCRIPT K-Z AGGREGATE INVENTORY CLASS.
29400 C K=1- FINISHED ITEMS.
29500 C K=2- INTERMEDIATE MANUFACTURED ITEMS.
29600 C K=3- PURCHASED ITEMS.
29700 C K=4- OVERALL CLASS.
29800 C
29900 C
30000 C
30100 C CALCULATE TOTAL DOLLAR VALUE OF FINISHED GOODS INVENTORY.
30200 C
30300 C TVAL=0.0
30400 C VAL=0.0
30500 DO 570 II=1,5
30600 VAL=VAL+(IVRDF(II,1)*VALUE(II,1))
30700 570 CONTINUE
30800 AGGIVY(1)=VAL
30900 TVAL=TVAL*VAL
31000 ASTATZ(1,1,1)=VAL
31100 ASTATZ(5,1,1)=VAL
31200 ASTATZ(8,1,1)=VAL
31300 C
31400 C CALCULATE TOTAL VALUE OF INTERMEDIATE GOODS INVENTORY.
31500 C
31600 C VAL=0.0
31700 NVF=FIN+1
31800 DO 580 II=1,NVF
31900 VAL=VAL+(IVRDF(II,1)*VALUE(II,1))
32000 580 CONTINUE
32100 AGGIVY(2)=VAL
32200 TVAL=TVAL*VAL
32300 ASTATZ(1,1,2)=VAL
32400 ASTATZ(5,1,2)=VAL
32500 ASTATZ(8,1,2)=VAL
32600 C
32700 C CALCULATE TOTAL VALUE OF PURCHASED INVENTORY.
32800 C
32900 VAL=0.0
33000 NVF=HFG+1
33100 DO 590 II=1,NVF
33200 VAL=VAL+(IVRDF(II,1)*VALUE(II,1))
33300 590 CONTINUE
33400 AGGIVY(3)=VAL
33500 TVAL=TVAL*VAL
33600 ASTATZ(1,1,3)=VAL
33700 ASTATZ(5,1,3)=VAL
33800 ASTATZ(8,1,3)=VAL
33900 C
34000 C CALCULATE TOTAL VALUE OF ALL INVENTORIES.
34100 C
34200 AGGIVY(4)=VAL
34300 ASTATZ(1,1,4)=TVAL
34400 ASTATZ(5,1,4)=TVAL
34500 ASTATZ(8,1,4)=TVAL
34600 C
34700 C INITIALIZE WORK-IN-PROCESS INVENTORY.
34800 C
34900 WIF(INV)=0.0
35000 DO 700 II=1,5
35100 WIFP(II,1)=0.0
35200 WIFP(II,2)=0.0
35300 700 CONTINUE
35400 RETURN
35500 END
35600 SUBROUTINE ARRIVE(JJD,LOEPT)
35700 C
35800 C THIS SUBROUTINE PROCESSES THE ARRIVAL OF AN ORDER TO A MACHINE
35900 C GROUP. LOEPT IS THE NUMBER OF THE DEPARTMENT SENDING THE ORDER
36000 C TO THE CURRENT MACHINE GROUP. IF THE ORDER IS ARRIVING FROM
ANOTHER MACHINE GROUP WITHIN THE SAME DEPARTMENT, THE ORDER WILL
BE PUT INTO QUEUE TO ALLOW THE PRIORITY RULES TO ASSIGN THE ORDER
A PROPER PRIORITY. IF THE ORDER IS ARRIVING FROM "DELIVER", IDEPT
EQUALS ZERO(0).

COMMON /STV1,CLOCK,DTIME,PTIME,IDAY,IRON,IXECK,NCLEAR,IDAY,NSTP,
INSEX,IRONS,STD1),STAL.

COMMON /PROD(1,4),(200,1),INPROD(200,15),IROOT(993),WROOT(993,5)
1,WROUT(993,2),2,WROUT(993,2),VALUE(200,2),ASTAT(3,2,5,4),
21STAT(6,2,4),ISTAT(6,2,200),JSTAT(6,5,2,9,200),JSTAT2(6,2,5,200)
COMMON /PROD/ DFIN(20,4),IDEM(20,5),IPROD(20,52),IDFIN(20,5),WFIN,
IBS(200),ZARAY,IPRD9,FIN,MPRD,NUM,AGINV(4),APINV,NIWPS(6,2),
BLOG(200),OPRA(200),
COMMON /SHOP/ MDPT(11,10),MCHGRP(12,10),MACH(5,100),
INEX(5,100),IEXPT,MGPP,SHACH(4,100,3),JDATA(3,10),
2QJOB(4,10,3),MSTAT(3,10,3),QSTAT(6,5,2,9,11),QSTAT2(6,2,3,10)
COMMON /ORDERS/ INDEX(993,5),IROER(993,3),IORDER(993,20),NAVAIL,
INEXD(52),RIEVT,MHSD,MHPRD,MHARR,ORDER(993,9)

SETUP REFERENCE POINTERS
IPROD= ITEM NUMBER OF CURRENT ORDER
MROW= REFERENCE POINTER INTO "MROOT"
IROW= REFERENCE POINTER INTO "IROOT"

IRDERH(JOB,5)=IROER(JOB,5)+1
IPROD=IROER(JOB,1)
MROW=MROD(IPROD,3)+IROER(JOB,5)+1
IDEPT=MROOT(JOB,1)
IRON=MROOT(MROW)
MGR=MROOT(MROW)
IRDERH(JOB,3)=IDEPT
IRDERH(JOB,9)=MGR
MSTAT(2,4,2P,1)=MSTAT(2,4,2P,1)+1
STIME=STOUT(IROW,1)
ATIME=STOUT(IROW,1)+MDPT(INEX,9)+1
QJOB(3,4,2P,1)=QJOB(3,4,2P,1)+STIME
QJOB(3,4,2P,1)=QJOB(3,4,2P,1)+STIME
ORDER(JOB,3)=STIME
ORDER(JOB,9)=STIME

DETERMINE IF ARRIVAL IS FROM A DIFFERENT DEPARTMENT OR
AN ARRIVAL FROM ANOTHER MACHINE GROUP WITHIN THE
CURRENT DEPARTMENT.

JDEPT=IODEPT
IF((IDEPT.EQ.JDEPT) IODEPT=0
IF((IDEPT.EQ.JDEPT) JDEPT=100

DETERMINE IF WORKERS ARE CURRENTLY AVAILABLE.

DETERMINE IF THE PROPER MACHINE IS AVAILABLE
IF((MCHGRP(2,4,2P).EQ.0) GOTO 130

DETERMINE IF BOTH A WORKER AND MACHINE ARE AVAILABLE TO START
C PROCESSING THE CURRENT ARRIVAL (I.E. CASE 2)

120 CALL GETC (AN, MSPT, J, DEPT, HRE)

CALL GETC (AN, MSPT, J, HRE, MACH)

CALL COATAL (0.0, QSTAT (1, L, L, MGRP))

CALL COATAL (0.0, QSTAT (1, L, L, MGRP))

CALL STPROC (J, MGRP, HAN, MACH, QDR)

RETURN

C CURRENT ARRIVAL CANNOT START PROCESSING. PLACE IN QUEUE.

ORDER (JOB, 1) = CLOCK

XX = QSTAT (1, L, L, MGRP) + 1.0

CALL COATAL (XX, CLOCK, QSTAT (1, L, L, MGRP))

QDATA (1, MGRP) = QDATA (1, MGRP) + ORDER (JOB, 8)

QDATA (2, MGRP) = QDATA (2, MGRP) + OREXR (JOB, 9)

VAL = QDATA (1, MGRP) + QDATA (2, MGRP))/50.

CALL COATAL (VAL, CLOCK, QSTAT (1, L, L, MGRP))

CALL PUTJ (JOB, MGRP)

RETURN

END

SUBROUTINE COATAL (VALUE, XX)

C THIS SUBROUTINE COLLECTS DATA THAT CAN BE USED TO CALCULATE

C THE FOLLOWING STATISTICS: (1) SAMPLE MEAN; (2) STANDARD DEVIATION;

C THE STANDARD DEVIATION OF SAMPLE MEAN; (3) MINIMUM VALUE;

C MAXIMUM VALUE; AND (5) NUMBER OF OBSERVATIONS.

DIMENSION XX (1)

XX (1) = XXX (1) + VALUE

XX (2) = XX (2) + VALUE

XX (3) = XX (3) + 1.0

IF (VALUE .LT. XX (4)) XX (4) = VALUE

IF (VALUE .GT. XX (5)) XX (5) = VALUE

RETURN

END

SUBROUTINE COATAL (VALUE, CLOCK, XX)

DIMENSION XX (1)

TL = CLOCK - XX (4)

OV = XX (1)

XX (1) = VALUE

XX (2) = XX (2) + (TL * OV)

XX (3) = XX (3) + (TL * OV * OV)

XX (4) = CLOCK

IF (VALUE .LT. XX (5)) XX (5) = VALUE

IF (VALUE .GT. XX (5)) XX (5) = VALUE

RETURN

END

SUBROUTINE CLCD (IPADO)

COMMON /T/H/CLK, DTIME, PTIME, IDAY, JDAY, HNCR, MNCR, NCRAB, ...

COMMON /R/BOX /TD/V/DF, I.W.ED (100, 15), IROUT (993, 0, 993, 5)

COMMON /L/ROUT (993, 2, ROUT (993, 2), VALU (20, 2), ATOM (5, 2, 5, 4), ...

COMMON /2/STIM (6, 2, 0, 0), STAT (6, 2, 200), STAT (5, 2, 9, 200), STAT (6, 2, 5, 200)

COMMON /M/PROS (20, 4), IDEN (20, 5), (IFORV (20, 52), IFROV (20, 4), XFO, ...
48100  180(200),CARRY,MPROD,UFNM,MPUR,NOE,AGGIVY(4),WIPINV,WIPS(6,2),
48200  2BLG2(200),IPROD(200)
48300  COMMON /𝐽𝐴𝑇𝐸𝑋/ INDEX(993,5),IORDER(993,3),IORDER(993,20),NAVAIL,
48400  1HEED(52),SORT,IPOR,WR4AR,ORDER(993,9)
48500  COMMON /𝑁𝐶𝑁𝐿𝑡/ IOPT(13)
48600  IF(IPR0D.NE.0) GO TO 130
48700  DO 100 JPORD=1,MPORD
48800  CALL CDATA(JORD(JPORD),CLOCK,JSTAT2(1,1,5,JPORD))
48900  VAL=UPORD(JPORD)
49000  UPORD(JPORD)=1.0
49100  IF(VA.L.NE.JPORD(JPORD)) CALL CDATA(JORD(JPORD),CLOCK,
49200  1 JSTAT2(1,1,5,JPORD))
49300  CALL CDATA(CLOG(JPORD),CLOCK,JSTAT2(1,1,4,JPORD))
49400  VAL=BLG2(JPORD)
49500  SLOG(JPORD)=B2(JPORD)
49600  IF(VAL.NE.CLOG(JPORD)) CALL COATA2(CLOG(JPORD),CLOCK,
49700  1 JSTAT2(1,1,4,JPORD))
49800  100 CONTINUE
49900  C CANCEL ALL UNRELEASED PLANNED ORDERS AND RESET PLANNED
50000  C ORDER RELEASE LIST.
50100  C
50200  C
50300  IF(NPORD.EQ.0) RETURN
50400  NPORD=NPORD
50500  LPTR=NPORD
50600  110 JPORD=IORDER(NPORD,1)
50700  JSTAT4,1,JPORD)=JSTAT4,1,JPORD)+1
50800  IORDER(NPORD,1)=0
50900  IORDER(NPORD,2)=0
51000  IORDER(NPORD,3)=0
51100  IORDER(NPORD,1)=0
51200  ORDER(NPORD,1)=0.0
51300  ORDER(NPORD,2)=0.0
51400  LPTR=NPORD
51500  NPORD=INDEX(NPORD,2)
51600  IF(NPORD.NE.0) GO TO 110
51700  INDEX(LPTR,2)=NAVAIL
51800  NAVAIL=NPORD
51900  NPORD=0
52000  130 CONTINUE
52100  C
52200  C INSERT INDIVIDUAL ITEM CLEAR PROCEDURE.
52300  C
52400  C
52500  RETURN
52600  END
52700  C SUBROUTINE COMPLT(J32)
52800  C
52900  C THIS SUBROUTINE PROCESSES THE COMPLETION OF AN OPEN ORDER.
53000  C
53100  C COMMON /TIME/CLOCK,TIME,TIME,DOAY,(RUN),(WEEK),(CLEAR),(DAY),(STOL),
53200  C INDEX,INDEX,INDEX,INDEX,INDEX,INDEX,INDEX,INDEX,INDEX,
53300  C COMMON /ORDERS/ INDEX(993,5),IORDER(993,3),IORDER(993,20),NAVAIL,
53400  C 1HEED(52),SORT,IPOR,WR4AR,ORDER(993,9)
53500  COMMON /PROD1/ IYPROD(200,7),INV2I(200,15),JORDER(993),MAXINV(993,3)
53600  LIPROD(993,2),JSTAT4(993,2),VALUE(200,2),JSTAT2(5,2,5,4),
53700  JSTAT2(5,2,4),JSTAT6(5,2,200),JSTAT1(5,2,200),JSTAT6(5,2,2,200)
53800  COMMON /PROD2/ INDEX(20,4),INDEX(20,5),IORDER(20,5),JORDER(20,3),MAXINV(20,3),
53900  IORDER(20,2),CLOCK,INDEX,EINDEX,EINDEX,INDEX,EINDEX,EINDEX,
54000  2BLG2(200),UPORD(200)
IPROD=INORD(JOB,1)
IQTY=INORD(JOB,1)

UPDATE INVENTORY STATUS

INVRDF(IPROD,1)=INVRDF(IPROD,1)+IQTY
INVRDF(IPROD,4)=INVRDF(IPROD,4)-IQTY
REAL=INVRDF(IPROD,4)
CALL CADATA(REAL,CLOCK,STATS(1,1,3,IPROD))

REMOVE ORDER FROM PRODUCT OPEN-ORDER LIST

INVRDF(IPROD,9)=INVRDF(IPROD,9)-1
LAST=INDEX(JOB,5)
NEXT=INDEX(JOB,5)
IF(LAST.LT.0) INVRDF(IPROD,10)=NEXT
IF(LAST.LE.0) INDEX(LAST,5)=NEXT
IF(NEXT.LE.0) INDEX(NEXT,5)=LAST

REMOVE ORDER FROM NEED WEEK LIST

LAST=INDEX(JOB,3)
NEXT=INDEX(JOB,3)
IDUE=INORD(JOB,3)-IWEK+1
IF(IDUE.LT.1) IDUE=1
IF(LAST.LT.0) NEED(IDUE)=NEXT
IF(LAST.LE.0) INDEX(LAST,4)=NEXT
IF(NEXT.LE.0) INDEX(NEXT,3)=LAST

PLACE STORAGE AREA BACK INTO AVAILABLE AREA

INDEX(JOB,1)=1
INDEX(JOB,2)=NAIL
INDEX(NAIL,1)=JOB
NAIL=JOB

CALCULATE ORDER STATISTICS

TTIME= TOTAL TIME(PLANTIME) IN SYSTEM(IN STANDARD DAYS)
WTIME= TOTAL QUEUE TIME FOR ORDER(IN STANDARD DAYS)
LATE= TOTAL DAYS LATE(NEGATIVE OR EARLY(POSITIVE))

TTIME=NAIL-INORD(JOB,6)+1
WTIME=-(ORDER(JOB,3)+ORDER(JOB,4))/STDAY
LWY=INDEX-INORD(JOB,3)
DAY=1DAY=1
IF(LWY.LT.0) DAY=DAY-5
IF(LWY.LT.0) LWY=LWY+1
TDATE=(5.0*LWY)+DAY

COLLECT PRODUCT ORDER AND INVENTORY STATISTICS.

CALL CADATA(TTIME,STATS(1,1,1,IPROD))
IF(IPROD.EQ.WP) CALL CADATA(TTIME,STATS(1,2,IPROD))
CALL CADATA(TDATE,STATS(1,3,IPROD))
CALL CADATA(TLATE,STATS(1,4,IPROD))
VAL=INORD(JOB,4)
VAL2=INORD(JOB,13)
VAL=VAL2+VAL
IF(VAL.LT.0) VAL=VAL-VAL2
VAL=INVRDF(IPROD,1)+INVRDF(IPROD,2)
CALL COATA2(V,A,L,CLOCK,OSTATZ(1,1,1,1),(PRO6D))

TAL=TAL*VALUE(PRO6D,1)

CALL COATA2(V,A,L,CLOCK,OSTATZ(1,1,2,1),(PRO6D))

CALL COATA2(V,A,L,CLOCK,OSTATZ(1,1,3,1),(PRO6D))

COLLECT DATA BY PRODUCT CLASS(FINISHED,INTERMEDIATE,PURCHASED).

IND=1

IF(PRO6D.ST.WFIN.AND.PRO6D.LE.4FG) INO=2

IF(PRO6D.ST.4FG) INO=3

CALL COATA1(TIME,ASTATI(1,1,1,1,IND))

CALL COATA1(TIME,ASTATI(1,1,1,2,IND))

CALL COATA1(TIME,ASTATI(1,1,1,3,IND))

CALL COATA1(TIME,ASTATI(1,1,1,4,IND))

IF(TIME gt.20.0) CALL COATA1(TIME,ASTATI(1,1,1,4,IND))

AGGINV(IND)!=AGGINV(IND)+(IETY*VALUE(PRO6D,1))

CALL COATA2(AGGINV(IND),CLOCK,ASTATZ(1,1,1,IND))

CALL COATA1(TIME,ASTATI(1,1,1,4))

CALL COATA1(TIME,ASTATI(1,1,1,4))

CALL COATA1(TIME,ASTATI(1,1,1,4))

CALL COATA1(TIME,ASTATI(1,1,1,4))

CALL COATA2(WIPIN,WIPNV,CLOCK,WIPSZ(1,1))

AGGINV(4)!=AGGINV(4)+(IETY*VALUE(PRO6D,1)-3025R(JOB,5))

CALL COATA2(AGGINV(4),CLOCK,ASTATZ(1,1,1,4))

CLEAR OUR ORDER RECORD

DO 100 I=1,20

IND=1

JRBH(JOB,1)=0

CONTINUE

DO 110 I=1,9

ORDER(JOB,1)=0

CONTINUE

DO 120 I=1,9

INDEX(JOB,1)=0

CONTINUE

IND=1

JRBH(JOB,1)=0

CONTINUE

IND=2

JRBH(JOB,2)=0

CONTINUE

IND=3

JRBH(JOB,3)=0

END

SUBROUTINE DAILY

THIS SUBROUTINE CONTROLS ALL DAILY AND WEEKLY PLANNING FUNCTIONS.

END OF THE DAY(TIME, "TIME") AND THE BEGINNING OF

THE NEXT DAY. IF THE CURRENT DAY IS THE END OF A WEEK,

THE WEEKLY PLANNING FUNCTIONS ARE INVOVED AND THE NEW

WEEK BEGINS.

COMMON /THRL/CLOCK,TIME,PTIME,TAOAI,IRUN,WEED,MCLEAR,MAAAM,AMST,P,

IMLOG,MRUN,STOWN,YWAL

COMMON /ORDRS/ IND(99,3),JRBH(999,3),INDS(999,20),NAVAIL,

INDH(52),NEXIT,NORD,WMAM,ORDER(999,9)

COMMON /WIP/ WIPST(999,2),WS(20,52),WRRP(200,52),WRLW(999,3),

INHAP

COMMON /JMB/ IFLAG(7),JFLAG(3),KFLAG,IXHAP,IPRO6D,AXL0AD(3)

COMMON /CMYLL/ IQOPT(11)

CHECK FOR THE END OF THE CURRENT WEEK.
66100 IF(IWEEX.EQ.0) GOTO 100
66200 IF(IDAY.LT.5) GOTO 150
66300 C CHECK FOR END OF SIMULATION
66400 C IVAL=0
66500 C IF(IWEEX.GT.IDOPT7.AND.IWEEX.LE.IDOPT8) IVAL=1
66600 CALL REPORT1(1,IVAL)
66700 IF(IWEEX.EQ.NCLEAR) CALL ENDRUN
66800 IF(IWEEX.LT.NSTOP) GOTO 100
67100 C END OF CURRENT OBSERVATION PERIOD.
67200 C CALL ENDRUN
67300 C NSTOP=NSTOP+1WEEK
67400 C IRUN=IRUN+1
67500 C IF(IRUN.GE.NRUNS) CALL ENDSIM
67600 C PLAN FOR NEXT WEEK
67700 C 100 IWEEX=IWEEX+1
67800 C NPT=NEED(1)
67900 C IF(NPT.NE.0) GOTO 110
68000 NEED(I)=NEED(I+1)
68100 C GOTO 130
68200 C 110 IF(INDEX(NPTR,4).EQ.0) GOTO 120
68300 C NPT=INDEX(NPTR,4)
68400 C GOTO 110
68500 C 120 INDEX(NPTR,4)=NEED(I)
68600 C IF(NEED(2).LE.0) INDEX(NEED(2),3)=NPTR
68700 C 130 DO 140 I=2,51
68800 C 140 CONTINUE
68900 C IDAY=1
69000 CALL FROST
69100 CALL DDE
69200 C IF(IWEEX.GT.NCLEAR.AND.IWEEX.LT.NSTOP) KFLAG=1
69300 C IF(IDOPT1.LE.1) CALL MASTER
69400 C IF(IDOPT1.LE.0) CALL MRP
69500 C IDAY=0
69600 KFLAG=0
69700 C 200 CONTINUE
69800 C START NEW DAY
69900 C
70000 C 150 IDAY=IDAY+1
70100 C NDAY=IDAY+1
70200 C CALL OHAND
70300 C IF(IDOPT1.LE.2) CALL MASTER
70400 C IF(IDOPT1.LE.2) CALL MRP
70500 C CALL DELT
70600 CALL DVAR
70700 DTIME=CLOCK+STODAY
70800 RETURN
70900 C ENDSIM
70900 C SUBROUTINE DELT
71000 C THIS SUBROUTINE RELAYS ORDERS TO THE SHOP FLOOR. EACH
71100 C PLANED ORDER RELEASE IS CHECKED TO DETERMINE IF SUFFICIENT
71200 C COMPONENTS ARE AVAILABLE TO COVER THE ORDER.
COMMON \ST(20)\CLOCK\DOLLAR\PTIME\DAY\ISUN\IMON\IMDAY\HOUR\MIDAY\MSTP
1 WEEK\WEEK\STORE\SUNDAY\HOUR
COMMON \GLMITS\MLTXY\MXCOM\XMP\XME\XJ\XGM\XGR\XGMP\XLAB\XJ\MLT
1 MXCH\MLTXY\MSTP\MX
COMMON \PROP1\INVP(200,4),INVP(200,3),IROUT(993),IROUT(993,5)
1 \XROUT(993,2),XMP\\XME\XJ,VALUE(20,2),XSTATE(5,2,5,4)
2ASTATE(5,2,4),XSTATE(5,2,4),XSTATE(5,2,9,200),XSTATE(5,2,5,200)
COMMON \PROP2\OFUN(20,4),IDEN(20,5),IFORE(20,50),IDFNM(20,50),IFLAT
1 130(200),CARRY\XMD\XFIN\XMD\XMD\XMD\XMD\XMD\XMD\XMD\XMD\XMD
2BLD(200),IF(200)
COMMON \SHOP1\MDP(11,11),MDP(12,10),XACH(5,100),XACH(5,100)
1 XEN(5,100),XJOB,MDP\MDP(4,100,3),XDATA(3,10)
20XJOB(4,100,3),XDATA(3,10),XSTATE(5,2,9,11),XSTATE(5,2,9,11)
COMMON \ORDER1\INDEX(993,6),IORDER(993,1),IORDER(993,2),IORDER(993,3)
1 XSTATE(5,2,9,11),XSTATE(5,2,9,11),XSTATE(5,2,9,11)
COMMON \ORDER2\IFLAT(993,2),XMP(20,50),XMD(20,50),XMD(20,50),XMD(20,50)
1 XMD(20,50),XMD(20,50),XMD(20,50),XMD(20,50),XMD(20,50)
COMMON \ORDER3\ORDER(13)
DATA ORDER/0
4100 C THIS SECTION LOCATES THE CURRENT ORDER AND DETERMINES IF THE
4200 ORDER IS FOR A MANUFACTURED ITEM OR A PURCHASED ITEM.
4300 C
4400 C JOB=TPRE
4500 IF (JOB=22.9) RETURN
4600 IF (IORDER(JOB,1).LE.0) WRITE(3,901) IORDER(JOB,1),XSTATE,DAY
4700 9001 FORMAT("ERROR AT START OF DELIVER",315)
4800 IF (IORDER(JOB,1).GT.0) GOTO 150
5000 C THIS SECTION DETERMINES IF SUFFICIENT COMPONENT INVENTORY IS
5200 AVAILABLE TO ALLOW THE RELEASE OF THE CURRENT ORDER.
5300 C
5500 .ISIZE=IORDER(JOB,1)
5600 IF (INSTR(HIPROD,3).EQ.0) GOTO 140
5700 IFST=INSTR(HIPROD,4)
5800 ISTATE=INSTR(HIPROD,3)-1
5900 IFLAG=1
6000 DU 110 IF=EPST,ISTATE
6100 ICOME=STATE(I1,1)
6200 ISTATE(STATE(I1,1)*STATE(I1,2)) STATE(I1,1)
6300 DIFF=LOGIC(ICOME)-INSTR(ICOME,1)
6400 IF (DIFF.LT.0.0) DIFF=0.0
6500 CALL CDATE(DIFF,STATE(1,4),STATE(1,4),STATE(1,4),STATE(1,4))
6600 IF (INSTR(STATE(I1,1),STATE(I1,4),STATE(I1,4),STATE(I1,4),STATE(I1,4))
6700 JSIZE=INSTR(STATE(I1,1),STATE(I1,4)) STATE(I1,4)
6800NSTATE(I1,3)=STATE(I1,3)+1
6900 IF (LOGIC(ICOME,2),STATE(I1,4),STATE(I1,4)=STATE(I1,4)+STATE(I1,4)
7000 IF (IFLAG.GE.1) CONTINUE
7100 ISTATE=JSIZE
7200 110 CONTINUE
7300 C THIS SECTION ATTEMPTS TO RELEASE THE CURRENT ORDER
7400 WITH A REDUCED LOT SIZE.
7500 C
7600 IF (IFLAG.GE.1) GOTO 120
7700 IF (IORDER(JOB,1).NE.INVP(IFPROD,5).AND.ISTATE.GT.INVP(IFPROD,5))
7800 L GOTO 120
IF (IREF(J28,1).LT.INVREQ(IPROD,5).AND.ISIZE.LT.IREF(J28,1))
7800  1   GOTO 170
78100  ISTAT(I,1,IPROD)=ISTAT(I,1,IPROD)+1
78400  C
78500  C  UPDATE UNALLOCATED AND ALLOCATED INVENTORIES LEVELS TO REFLECT
78600  C  ORDER RELEASE.
78700  C
78800  120  DO 130 II=FIRST,ILAST
78900  IC04=NBILL(II,1)
79000  IQTY=ISIZE*NBILL(II,2)
79100  INVROP(IC04,1)=INVROP(IC04,1)-IQTY
79200  INVROP(IC04,2)=INVROP(IC04,2)+IQTY
79300  BLOG(IDC04)=BLOG(IDC04)-IQTY
79400  C
79500  130  CONTINUE
79600  C
79700  140  SIZE=ISIZE
79800  CALL CODATA(SIZE,OSTAT(1,1,5,IPROD))
79900  SIZE=IREF(J28,1)
80000  CALL CODATA(SIZE,OSTAT(1,1,7,IPROD))
80100  INO=1
80200  IF(IPROD.0.TNFIN.0.AND.IPROD.0.0.MFG) INO=2
80300  IF(IPROD.0.TNFG) INO=3
80400  NREL=NPRL-1
80500  REAL=0AY-INVROP(IPROD,11)
80600  INVROP(IPROD,11)=0
80700  CALL CODATA(REAL,OSTAT(1,1,5,IPROD))
80800  IOREQ(J28,2)=IWEK
80900  CALL CODATA(REAL,OSTAT(1,1,5,INO))
81000  CALL CODATA(REAL,OSTAT(1,1,5,4))
81100  IOREF(J28,1)=ISIZE
81200  C
81300  C  SETUP ORDER ARRAYS
81400  C
81500  C  IREDF(I,L) Z ORDER MASTER RECORD(FULL WORD INTEGR).
81600  C
81700  C  SUBSCRIPT I Z ORDER RECORD NUMBER.
81800  C
81900  C  SUBSCRIPT J Z DATA TYPE IDENTIFIER.
82000  C  J=1- ORDER QUANTITY.
82100  C  J=2- RELATIVE(SEQUENTIAL) ORDER NUMBER.
82200  C  J=3- CUMULATIVE DEMAND SINCE ORDER RELEASE.
82300  C
82400  C
82500  C  IREDF(I,L) Z ORDER MASTER RECORD(HALF WORD INTEGER).
82600  C
82700  C  SUBSCRIPT I Z ORDER RECORD NUMBER.
82800  C
82900  C  SUBSCRIPT J Z DATA TYPE IDENTIFIER.
83000  C  J=1- ITEM NUMBER.
83100  C  J=2- RELEASE WEEK.
83200  C  J=3- DUE WEEK(OFFER DUE DATE).
83300  C  J=5- CURRENT OPERATION NUMBER OR DAY OF ARRIVAL IF IN
83400  C  ORDER FOR A PURCHASED ITEM.
83500  C  J=6- RELEASE DAY OF ORDER(ABSOLUTE).
83600  C  J=7- RELEASE DAY(DAY OF WEEK).
83700  C  J=8- CURRENT DEPARTMENT NUMBER.
83800  C  J=9- CURRENT MACHINE GROUP NUMBER(FACTUAL).
83900  C  J=10- CURRENT MACHINE NUMBER(=J*2 IN QUEUE OR >J*2 IN PROCESS).
84100 C J=11 - CURRENT WORKER NUMBER (ACTUAL).
84200 C J=12 - DEPARTMENT NUMBER OF NEXT OPERATION.
84300 C J=13 - MACHINE GROUP NUMBER OF NEXT OPERATION.
84400 C J=14 - NOT USED.
84500 C J=15 - NOT USED.
84600 C
84700 C
84800 C ORDER(I, J) = Z ORDER MASTER RECORD (FULL WORD REAL).
84900 C SUBSCRIPT I = Z ORDER RECORD NUMBER.
85000 C SUBSCRIPT J = Z DATA TYPE INDICATOR.
85100 C J=1 - TIME ORDER WILL END PROCESSING AT CURRENT MACHINE
85200 C OR
85300 C J=2 - TIME OF ENTRY TO QUEUE.
85400 C J=3 - ORDER PRIORITY.
85500 C J=4 - CUMULATIVE SETUP TIME INCURRED.
85600 C J=5 - CUMULATIVE RUN TIME INCURRED IN MINUTES (ACTUAL).
85700 C J=6 - CURRENT VALUE OF ORDER IN DOLLARS.
85800 C J=7 - ACTUAL CLOCK TIME WHEN ORDER ENTERED SYSTEM.
85900 C J=8 - SUM OF REMAINING WORK (SETUP & RUN TIMES IN MINUTES).
86000 C J=9 - SETUP TIME FOR CURRENT OPERATION (IN MINUTES).
86100 C J=10 - RUN TIME FOR CURRENT OPERATION (IN MINUTES).
86200 C
86300 C
86400 C
86500 C
86600 C
86700 C
86800 C INDEX (I, 1) - pointer to last entry in Z (1) future event list;
86900 C (2) machine group queue; or (3) planned order
87000 C INDEX (I, 2) - pointer to next entry in Z (1) future event list;
87100 C (2) machine group queue; or (3) planned order
87200 C
87300 C INDEX (I, 3) - pointer to last entry in due week list.
87400 C INDEX (I, 4) - pointer to next entry in due week list.
87500 C INDEX (I, 5) - pointer to last entry in product order list.
87600 C INDEX (I, 6) - pointer to next entry in product order list.
87700 C
87800 C
87900 C
88000 C
88100 C
88200 C 150 ORDER = ORDER + 1
88300 C INDEX (JOB, 2) = ORDER
88400 C INDEX (JOB, 3) = 0
88500 C INDEX (JOB, 4) = 0
88600 C INDEX (JOB, 5) = 0
88700 C INDEX (JOB, 6) = IDAY
88800 C INDEX (JOB, 7) = IDAY
88900 C INDEX (JOB, 8) = 0
89000 C INDEX (JOB, 9) = 0
89100 C INDEX (JOB, 10) = 0
89200 C INDEX (JOB, 11) = 0
89300 C INDEX (JOB, 12) = 0
89400 C INDEX (JOB, 13) = 0
89500 C INDEX (JOB, 14) = 0
89600 C INDEX (JOB, 15) = 0
89700 C ORDER (JOB, 1) = 0.0
89800 C ORDER (JOB, 4) = 0.0
89900 C ORDER (JOB, 5) = 0.0
90000 C ORDER (JOB, 6) = CLOCK
ORDER(JOB,3)=0.0
ORDER(JOB,3)=0.0
ISTAT(2,1,IPROD)=ISTAT(2,1,IPROD)+1
C
C UPDATE UNRELEASED PLANNED ORDER QUANTITY STATISTICS.
C
UPOR(IPROD)=UPOR(IPROD)-IRDER(JOB,1)
CALL COATAC(UPOR(IPROD),CLOCK,OSTAT(1,1,5,IPROD))
C
C REMOVE PLANNED ORDER FROM RELEASE LIST.
C
LAST=INDEX(JOB,1)
NEXT=INDEX(JOB,2)
IF(LAST.EQ.0) NPROD=NEXT
IF(LAST.NE.0) INDEX(LAST,2)=NEXT
IF(NEXT.NE.0) INDEX(NEXT,1)=LAST
IF(IRDER(JOB,1).LT.469) GOTO 170
C
C DETERMINE TOTAL PROCESSING TIME SETUP PLUS RUN TIME.
C
TTIME=0.0
IFIRST=INWROD(IPROD,3)
ILAST=IFIRST+INWROD(IPROD,7)-1
IQTY=IRDER(JOB,1)
DO 160 II=IFIRST,ILAST
160 IPTR=IROUT(II,3)
TIME=TTIME+(II*IROUT(II,2))+IROUT(II,1)
CONTINUE
ORDER(JOB,7)=TIME
CALL ARRIVE(JOB,0)
GOTO 180
C
C THIS SECTION PROCESSES A PURCHASE ORDER RELEASE
C
170 IRDER(JOB,5)=(IRDER(JOB,3)-1)*5
MTPR=IRMPR
CALL SORT(JOB,NPTA,5,1,2)
NRMPR=IRPTA
C
C PUT OPEN ORDER INTO WEEK LIST AND PRODUCT LIST
C
180 IDUE=IRDER(JOB,3)-1
IF(IDUE.LE.1) IDUE=1
CALL SORT(JOB,MSD(IDUE),1,3,4)
CALL SORT(JOB,IDUE,INWROD(IPROD,19),6,5,5)
INWROD(IPROD,9)=INWROD(IPROD,9)+1
INWROD(IPROD,4)=INWROD(IPROD,4)+IRDER(JOB,1)
REAL=INWROD(IPROD,4)
CALL COATAC(REAL,CLOCK,OSTAT(1,1,3,IPROD))
C
190 JOB=JOB
IF(JOB.NE.0) GOTO 100
RETURN
C
C THIS SUBROUTINE GENERATES DEMAND FOR ALL INDEPENDENT DEMAND ITEMS
C
COM=' /T=1/CLOCK,TIME,PIF,DATE,IRUN,INWEEK,TIME,CLEAR,NOAV,
ST,TIME,INWEEK,HEAT,ST,DATE,ST,VAL
COM=' /NOT=1/INDEX(993,6),IRDER(993,3),IRDER(993,20),NAVAIL,
1NEED(53), IENEG, INPROD, IHRMARR, ORDER(993,9)
1COMN /PROD1/ INPROD(200,7), INPROD(200,15), INOUT(393), INOUT(993,5)
1PROD(993,2), OUT(993,2), VALUE(200,2), ASTAT1(5,2,5,4),
2ASTAT2(6,2,5,4), ISSTAT(6,2,200), JSTAT(6,2,9,200), JSTAT(6,2,5,200)
1COMN /PROD2/ DFUN(20,4), IDEN(20,5), IFOR(2052), IDFUN(203), MFG,
1J30(200), CARRI, INPROD, IINF, INPR, NDEN, AGGIV(4), ZigIV, VIPS(6,2),
2BLOC(200), UPDR(200)
96100 DO 100 II = 1, NDAY
96200 IPRD = IDENT(II, 1)
96300 SAVE = 30(IPROD)
96400 JDEN = IDENT(II, IDAY) + 30(IPROD)
96500 ISALES = JDEN
96600 IF(JDEN .GT. INVROF(IPROD, 1)) ISALES = INVROF(IPROD, 1)
96700 B0(IPROD) = JDEN - ISALES
96800 INPROD(IPROD, 1) = INVROF(IPROD, 1) - ISALES
96900 VAL = INVROF(IPROD, 1) + INVROF(IPROD, 2)
97000 CALL CDA2(VAL, CLOCK, OSTAT2(1, 1, 1, IPROD))
97100 VAL = VAL * VALUE(IPROD, 1)
97200 CALL CDA2(VAL, CLOCK, OSTAT2(1, 1, 2, IPROD))
97300 VAL = ISALES * VALUE(IPROD, 1)
97400 IND = 1
97500 IF(IPROD .GT. MFG AND IPROD .LT. MFG) IND = 2
97600 IF(IPROD .GT. MFG) IND = 3
97700 AGGIV(IND) = AGGIV(IND) - VAL
97800 CALL CDA2(AGGIV(IND), CLOCK, OSTAT2(1, 1, IND))
97900 AGGIV(4) = AGGIV(4) - VAL
98000 CALL CDA2(AGGIV(4), CLOCK, OSTAT2(1, 1, 4))
98100 C ADJUST BACKORDER QUANTITIES AND STATISTICS.
98200 C
98300 C
98400 C
98500 C
98600 C
98700 C
98800 C
98900 C
99000 C
99100 C
99200 C
99300 C
99400 100 CONTINUE
99500 RETURN
99600 END
99700 C SUBROUTINE DEMAND
99800 C
99900 C THIS SUBROUTINE CALCULATES THE DAILY DEMAND FOR EACH END
ITEM.

COMMON \TIME1/CLOCK,DTIME,PTIME,IDAY,IEUN,IEEK,NCLEAR,NDAY,NSTOP,

IWEED,NWEED,STOAY,BVAL

COMMON /ORDERS/ INOX(993,6),INOERP(993,3),ORDERN(993,20),NATAL,

INENO(52),NOVNT,NOPRD,NOWARR,ORDER(993,9)

COMMON /PROD/ INWRF(200,7),INVRO(100,15),CTOUT(993),XCTOUT(993,5)

COMMON /RST/ KORD(993,2),KOUT(993,2),VALUS(200,2),ASTATL(5,2,5,4)

COMMON /PROD/ DFUN(20,4),DEF(20,5),IFORE(20,52),IFUN(20,3),XFLG,

180(200),CARRY,FPIC,INF,IFP,IMOE,AGSINV(4),IIPINV,IIPS(5,2),

290(200),UPD(200)

COMMON /SORT/ SSAYE(10),ICLOSE,IX

DIMENSION R(3)

DO 120 II=1,NOEY

160 IFDMD=IFORE(II,1)+FORE(II)

170 BASE=0.0

180 DO 190 J=1,5

190 RN=RAN(0)

200 BASE=BASE+RN

RF(J)=RN

220 CONTINUE

230 DO 110 JS=0

240 DO 110 J=1,4

250 IFDMD(J)=IPOE*RF(J)/BASE

260 IFDMD=ISUM+IFDMD(J)

270 CONTINUE

280 IFDMD(II,5)=IFDMD-150

290 CONTINUE

300 RETURN

310 END

SUBROUTINE ENDRUN

330 COMMON /TIME1/CLOCK,DTIME,PTIME,IDAY,IEUN,IEEK,NCLEAR,NDAY,NSTOP,

340 IWEED,NWEED,STOAY,BVAL

350 COMMON /SHOP/ MDSTL(11,10),MDRGR(12,10),MDRCH(5,100),

350 IWEED(4,100),MDRCH,MDRGR,SMACH(5,100,3),MDSTL(3,10),

370 2JDBE(4,10,1),ISTATL(3,9,3),JSTATL(5,2,9,11),JSTATL(5,2,3,10)

380 COMMON /PROD/ INWRF(200,7),INWROH(200,15),JROUT(993),XROUT(993,5)

390 COMMON/LSTH/5073,2,JROUT(993,2),JVALUES(200,2),JSTATL(5,2,5,4),

400 2JSTATL(5,2,4),ISTATL(5,2,200),JSTATL(5,2,9,200),JSTATL(5,2,5,200)

410 COMMON /CPFL/ IDPC(13)

420 IFALL=0

430 IFALL=2

440 IF(IWEED.EQ.NCLEAR.AND.IDPC(3).EQ.1) IFALL=1

450 IF(IWEED.EQ.2)NCLEAR.AND.IDPC(3).EQ.1) IFALL=1

460 IF(IWEED.EQ.NCLEAR.AND.IDPC(5).EQ.1) IFALL=1

470 IF(IWEED.EQ.NCLEAR.AND.IDPC(5).EQ.1) IFALL=1

480 CALL REPORT(1,IFALL)

490 CALL REPORT(2,IFALL)

500 RETURN

510 END

SUBROUTINE ENDRUN

530 COMMON /SORT/ SSAYE(10),ICLOSE,IX

540 COMMON /SORT/ BORD(200),TSLTJ(10),TJJAD(10),TFVAL(7),CTUE(10),

550 LATNY(200)

560 COMMON /TIME1/CLOCK,DTIME,PTIME,IDAY,IEUN,IEEK,NCLEAR,NDAY,NSTOP,

570 IWEED,NWEED,STOAY,BVAL

580 COMMON /PROD/ INWRF(200,7),INWROH(200,15),JROUT(993),XROUT(993,5)

590 COMMON/LSTH/5073,2,JROUT(993,2),JVALUES(200,2),JSTATL(5,2,5,4),

600 2JSTATL(5,2,4),ISTATL(5,2,200),JSTATL(5,2,9,200),JSTATL(5,2,5,200)
COMMON /P300, QOSN(20,4), IDSN(20,5), IFOSN(20,52), IDFSN(20,5), HGF,
QSS(200), HSF, HPS30, MFL, MFLY, HPS3, HPS7, HPS8, HPS9, HPS10,
HFSN, IQOSN, IQOSN, IQOSN, IQOSN, IQOSN, IQOSN, IQOSN, IQOSN,
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IQOSN, IQOSN, IQOSN, IQOSN, IQOSN, IQOSN, IQOSN, IQOSN,
LNSWEEK,WRNWS,STDDAY,STAT

COMMON /IPRD/INVRSF(200,7),INVRDH(200,15),IREOU(993),WROUT(993,5)

L,HROUT(993,2),OROUT(993,2),VALUE(200,20),STAT(5,2,5,2)

LASTAT(5,2,4),ESTAT(5,2,4),JSTAT(5,2,9,200),JSTAT(5,2,5,200)

COMMON /SSHPIL/. SSHPIL(11,10),CMCHR(12,10),MACH(5,100)

L,EROUT(100,3),EROUT(100,3),EROUT(100,3)

QJOCS(4,10,3),QSTAT(3,10,3),QSTAT(3,10,3),QSTAT(2,1,3,3)

COMMON /ORDERS/ INDEX(993,5),IORDERH(993,3),IORDERH(993,20),HNAVAIL,
INREP(52),XNVT,WRP,DWHRRCR,ORDR(993,9)

COMMON /HREU/. HREU(993,2),HPS(20,51),HREU(993,20),HREU(993,5),
INREP

JOB=I2VT

NEVENT=INDEX(JOB,2)

INDEX(JOB,2)=0

IF(NEVENT.NE.0) GOTO 100

PTIME=10.0**10.0

GOTO 110

100 INDEX(NEVENT,1)=0

PTIME=IORDER(NEVENT,1)

C

Determine which resources were in use.

C

110 IORDERH(JOB,3)

LDEPT=IDEPT

HCGRP=IORDERH(JOB,3)

14600 MACH=IORDERH(JOB,11)

14700 MAN=IORDERH(JOB,11)

14800 IORDERH(JOB,9)=0

14800 IORDERH(JOB,9)=0

14900 IORDERH(JOB,10)=0

15000 IORDERH(JOB,11)=0

15100 IORDERH(JOB,11)=0

15200 IORDERH(JOB,11)=0

15300 MSTAT(3,HCGRP,1)=MSTAT(3,HCGRP,1)+1

C

15400 C

C

RESET STATUS INDICATORS AND POINTERS FOR RELEASED WORKER AND MACHINE.

C

15600 C

C

15700 C

C

15800 C

C

15900 MACH(2,MACH)=0

16000 MACH(3,MACH)=0

16100 MACH(2,MACH)=0

16200 MACH(3,MACH)=0

16300 CALL PUTM(ICA,HCGRP(2,HCGRP),MACH)

16500 IF(OP.EQ.INVRDH(IPROD,7)) CALL COMPLT(JOB)

16700 IF(OP.EQ.INVRDH(IPROD,7)) CALL ARRIVE(JOB,LDEPT)

16800 IFLAG=3

16900 CALL SELECT(IORDERH,HCGRP,JOBS)

17000 IF(IFLAG.EQ.2) AND HCGRP.EQ.2 CALL PUTM(MAN,HCGRP(2,IORDERH),MEN)

17100 IF(MCGRP.EQ.0) RETURN

17200 CALL GETH(ICA,HCGRP(2,HCGRP),MACH)

17300 IF(IFLAG.EQ.1) CALL GETH(MAN,HCGRP(2,IORDERH),MEN)

17400 C GET ROUTING INFO.

17500 IF(IPROD.EQ.IORDERH(JOB,1))

17600 MACH=MACH(IPROD,4)+IORDER(JOB,5)-1

17700 IROW=MACH(JOB,3)

17800 CALL ST2RCC(JOB,HCGRP,MACH,MCIC,MCIC)

17900 IFLAG=IFLAG+1

18000 IF(LDEPT.EQ.0 AND IFLAG.EQ.1) GOTO 130
RETURN
END

FUNCTION FSTERR(II)

COMMON /PROJ2/ OFUN(20,4), IDEF(20,5), IFREQ(20,52), IDIN(20,3), WPS, ILO(200), CARRY, NPROD, NFIN, NPUR, NOEY, AGBY(4), WIPINV, WIPS(6,2),

COMMON /BTR1/ SSAVE(10), IICODE, IX

R2N=RAN(0)

FORERR=(R2N*OFUN(II,1)*OFUN(II,4))

VAL=RAN(0)

IF(VAL.LT.0.4999) FORERR=-FORERR

RETURN
END

SUBROUTINE FST3T

THIS SUBROUTINE GENERATES FORECASTS FOR ALL INDEPENDENT DEMAND ITEMS. THE FORECAST EXTENDS TO COVER THE ENTIRE MRP PLANNING HORIZON.

COMMON /TIME/CLOCK, OTIME, PTIME, IDAY, IRUN, IWEEK, NCLEAR, NDAY, NSTOP,

IWEEK, NRIPS, SPIX, SMVA, VAL

COMMON /PROJ2/ OFUN(20,4), IDEF(20,5), IFREQ(20,52), IDIN(20,3), WPS, ILO(200), CARRY, NPROD, NFIN, NPUR, NOEY, AGBY(4), WIPINV, WIPS(6,2),

29LOG(200), UFLG(200)

COMMON /MPR1/ HPILL(993,2), WPS(20,52), MRP(200,52), MBILL(993,6),

LMRP

DO 100 II=1,NOE

DO 100 JJ=1,MRP

IFREQ(II,JJ)=0

CONTINUE

DC 120 II=1,NOE

X=IWEEK-1

VAL=ANTY(II,2)

P1=1.145936/V1

DO 130 JJ=1,MRP

K1=X+1

R1=RI*V1

Y=SIN(R1)

IF(IDFNY(II,3).LT.2) Y=COS(R1)

23200 Y=Y*OFUN(II,1)

23200 IFREQ(II,JJ)=OFUN(II,1)*(1.0+OFUN(II,2)*K1)+(Y*OFUN(II,3))

CONTINUE

CONTINUE

RETURN

END

SUBROUTINE GETY(NPTR, WM, NN)

THIS SUBROUTINE IS USED TO LOCATE AND TRANSFER WORKERS AND MACHINES FROM ONE LISTS STRUCTURE TO ANOTHER. THE PARAMETER LIST Serves AS REFERENCE POINTS. "WM" REPRESENTS EITHER "MHP" OR "MHCP" DEPENDING ON WHICH WAS SPECIFIED WHEN THE SUBROUTINE WAS CALLED. "WM" REPRESENTS EITHER "MACH" OR "MAHP" AND IS ALSO SPECIFIED WHEN CALLING THE SUBROUTINE.

DIMENSION WM(1), WM(5,1)

C REMOVE FIRST ENTRY FROM LIST, DECREMENT COUNTER, AND UPDATE
C ALL POINTERS.

C MPR = MM(0)
C MM(2) = MN(5, MPR)
C IF (MM(2).EQ.0) MN(4, MM(2)) = 0
C MM(1) = MM(1) - 1

C PUT ENTRY INTO BUSY LIST, INCREMENT COUNTER, AND UPDATE
C ALL POINTERS.

C NN(5, MPR) = MM(4)
C IF (MM(4).NE.0) MN(4, MM(4)) = MPR
C M3(4) = MPR
C M3(3) = M3(3) + 1
C RETURN

C END
C SUBROUTINE GET1(HGRP, JOB)

C THIS SUBROUTINE REMOVES JOBS FROM QUEUE

C C6100 COMMON /V0ICE/ CLOCK, DTIME, PTIME, IDAY, IYEAR, IE25K, OUSER, IDAY, WSTDP,
C INDEX, WNBRR, ST0DAY, 2FL
C 6200 COMMON /SHSP/ KEPR(11, 10), MCHGRP(12, 10), WACH(5, 100),
C 6300 WBNR(5, 100), WDAY, WGRP, SMACH(4, 100), JDATA(3, 10),
C 6400 JDATA(4, 10, 1), WSTAT(3, 10, 3), OSTAT(5, 2, 9, 11), QSTAT(5, 2, 1, 10)
C 6500 COMMON /ORDERS/ INDEX(999, 6), IORDER(993, 3), IORDER(993, 25), ODATA,
C 6600 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 6700 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 6800 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 6900 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 7000 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 7100 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 7200 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 7300 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 7400 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 7500 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 7600 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 7700 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 7800 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 7900 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 8000 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 8100 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 8200 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 8300 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 8400 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 8500 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 8600 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 8700 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 8800 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 8900 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 9000 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 9100 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 9200 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 9300 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 9400 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 9500 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 9600 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 9700 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 9800 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 9900 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
C 10000 INDEX(52), KEVIT, WPOR, WRAPA, ORDER(993, 9)
INTEGER INET(52)
DO 10 II=1,52
INET(II)=NET(II)
10 CONTINUE
C
 THIS SECTION PROCESSES THE NET ARRAY IF THE DUE DATE UPDATING
 PROCEDURE IS NOT USED. THIS PROCESSING IS REQUIRED TO MAINTAIN
 A PROPER SEQUENCE OF ORDER RELEASES (I.E. ASCENDING DUE DATES BY
 RELEASE SEQUENCE).

IF(IDPT(3).EQ.1) GOTO 90
DO 50 II=1,52
50 IF(IDPT(11).EQ.0) GOTO 50
DO 20 JJ=1,II
IF(INET(JJ).LT.INVRDF(IPROD,5)) GOTO 30
20 CONTINUE
GOTO 50
30 NYAL=II-1
DO 40 KK=JJ,NYAL
40 INET(KK)=INET(KK)+SRECT(II)
31 CONTINUE
DO 50 JJ=1,II
IF(INET(JJ).LT.INVRDF(IPROD,5)) GOTO 30
50 CONTINUE
90 IRULE=INVRDF(IPROD,2)
GOTO(100,200,300,200,200),IRULE

C
LOT-FOR-LOT LOT SIZING RULE.

C
100 K=LT
110 K=K+1
3300 IF(K.LT.MARP) RETURN
3310 IF(INET(K).GE.INVRDF(IPROD,5)) GOTO 110
3320 IF(INET(K).LT.0) PORD(K-LT)=-INET(K)+INVRDF(IPROD,5)
3330 IF(INET(K).GT.0) PORD(K-LT)=INVRF(IPROD,5)-INET(K)
3340 IQTY=IPORD(K-LT)
3350 DO 120 JJ=K,MARP
3360 INET(JJ)=INET(JJ)+IQTY
120 CONTINUE
3380 IF(K.LT.MARP) GOTO 110
3390 RETURN

C
FIXED ORDER QUANTITY RULE.

C
200 K=LT
210 K=K+1
3400 IF(K.LT.MARP) RETURN
3410 IF(INET(K).GE.INVRDF(IPROD,5)) GOTO 210
3420 IQTY=INVRDF(IPROD,3)
3430 IF(IQTY-LT.1.0) IQTY=-INET(K)+INVRDF(IPROD,5)
3440 PORD(K-LT)=IQTY
3500 DO 220 JJ=K,MARP
3510 INET(JJ)=INET(JJ)+IQTY
220 CONTINUE
3530 IF(K.LT.MARP) GOTO 210
3540 RETURN

C
PERIODIC ORDER QUANTITY RULE.

C
300 K=LT
310 K=K+1
3600 IF(K.LT.MARP) RETURN
36100 IF(INST(X).GE.INTROP(IPROD,3)) GOTO 310
36200 PORD(X-LT)=INST(X+INTROP(IPROD,3)-1)
36300 IQTY=PORD(X-LT)
36400 DO 330 JJ=K,MRP
36500 INET(JJ)=INST(JJ)+IQTY
36600 CONTINUE
36700 IF(X+MRP) GOTO 310
36800 RETURN
36900 END
37000 SUBROUTINE MASTER
37100 C THIS SUBROUTINE DEVELOPS THE MASTER PRODUCTION SCHEDULE WHICH
37200 C SPECIFIES THE REQUIREMENTS FOR ALL INDEPENDENT DEMAND ITEMS.
37300 C
37400 COMMON /TWSI/CLOCK,DTIME,PTIME,TDAY,IRUN,INEW,NCLEAR,NDAY,NSP,
37500 INEQK,IRUNX,STDAY,EVER
37600 COMMON /IPRO2/ FENH(20,4), IDEH(20,5), IFORE(20,52), IFDUM(20,3), MFS,
37700 IFDUM(200), CARRY,NPROD,NPN,PPOR,NDME,AGGINW(4), IFIPW,NIPS(6,2),
37800 BLOG(200), NPRO(200)
37900 COMMON /HRP1/ NSHIL(993,2), MPS(20,52), MRP(200,52), NHILL(993,6),
38000 MRS
38100 COMMON /CHTIV/ IQTH(13)
38200 COMMON /CHTLIV/ IQTH(13)
38300 DO 110 II=1,NDME
38400 IF(IQTH(1).EQ.1) MPS(II,1)=((5.0-IDAY)/5.0)*IFORE(II,1)
38500 ISTAT=1
38600 IF(IQTH(1).EQ.1) ISTAT=2
38700 DO 110 JJ=ISTAT,MRP
38800 MPS(II, JJ)=IFORE(II, JJ)
38900 CONTINUE
39000 MPSD=IFDUM(II,1)
39100 MPS(II,1)=MPS(II,1)+BLOG(IIPROD)
39200 110 CONTINUE
39300 RETURN
39400 END
39500 SUBROUTINE MRP
39600 COMMON /IMPROD/ 4HST(11,10), MCHGRP(12,10), FACH(5,100),
39700 MACH(5,100), MGP, SHARP(4,100,3), JDATA(3,10),
39800 MACH(5,100), MGP, SHARP(4,100,3), JDATA(3,10),
39900 COMMON /CHT/ IQTH(13)
40000 COMMON /CHTL/ IQTH(13)
40100 COMMON /ISHP/ 4HST(11,10), MCHGRP(12,10), FACH(5,100),
40200 MACH(5,100), MGP, SHARP(4,100,3), JDATA(3,10),
40300 COMMON /ISHP/ 4HST(11,10), MCHGRP(12,10), FACH(5,100),
40400 MACH(5,100), MGP, SHARP(4,100,3), JDATA(3,10),
40500 COMMON /ISIP/ 4HST(11,10), MCHGRP(12,10), FACH(5,100),
40600 MACH(5,100), MGP, SHARP(4,100,3), JDATA(3,10),
40700 COMMON /ISIP/ 4HST(11,10), MCHGRP(12,10), FACH(5,100),
40800 MACH(5,100), MGP, SHARP(4,100,3), JDATA(3,10),
40900 COMMON /ISIP/ 4HST(11,10), MCHGRP(12,10), FACH(5,100),
41000 MACH(5,100), MGP, SHARP(4,100,3), JDATA(3,10),
41100 COMMON /ISIP/ 4HST(11,10), MCHGRP(12,10), FACH(5,100),
41200 MACH(5,100), MGP, SHARP(4,100,3), JDATA(3,10),
41300 COMMON /ISIP/ 4HST(11,10), MCHGRP(12,10), FACH(5,100),
41400 MACH(5,100), MGP, SHARP(4,100,3), JDATA(3,10),
41500 COMMON /ISIP/ 4HST(11,10), MCHGRP(12,10), FACH(5,100),
41600 MACH(5,100), MGP, SHARP(4,100,3), JDATA(3,10),
41700 COMMON /ISIP/ 4HST(11,10), MCHGRP(12,10), FACH(5,100),
41800 MACH(5,100), MGP, SHARP(4,100,3), JDATA(3,10),
41900 COMMON /ISIP/ 4HST(11,10), MCHGRP(12,10), FACH(5,100),
42000 CALL CLRD(IVAL)
C GENERATE PRODUCT EXPLOSION FOR ALL ITEMS
C
DO 250 IPROD=1,MPROD
C
C CLEAR OUT SCHEDULED RECEIPT ARRAY "SRECT" AND PLANNED ORDER
C
C RELEASE ARRAY "PORD".

C
DO 90 II=1,MHPAR
SRECT(II)=0
PORD(II)=0
90 CONTINUE

C LOCATE ALL OPEN ORDERS FOR PRODUCT "IPROD" AND PLACE IN SCHEDULED
C ARRAY("SRECT"). PAST DUE ORDERS ARE PLACED IN WEEK ONE.
C
IF(INVR1D(IPROD,9).LE.0) GOTO 104
IPTR=INVR1D(IPROD,10)
100 SRECT(IPTR)=SRECT(IPTR)+ORDR(IPTR,1)
IF(IPTR.5.EQ.0) GOTO 100
IPTR=INDEX(IPTR,5)
104 104 DO 105 II=1,MHPAR
REQT(II)=0
105 CONTINUE
NPAR=INVR1D(IPROD,5)
110 IF(NPAR.GT.0) GOTO 130
112 CONTINUE
AT THIS POINT THE CURRENT ITEM IS KNOWN TO HAVE INDEPENDANT DEMAND.
C
IND=IPROD
IF(IPROD.LE.NFINS) GOTO 115
IVAL=NFIN+1
600 DO 112 IND=IVAL,NBEA
620 IF(IPROD(IND,1).EQ.IPROD) GOTO 115
112 CONTINUE
AT THIS POINT THE CURRENT ITEM IS KNOWN TO HAVE BOTH INDEPENDANT

C
113 STOP
C
105 CONTINUE
IF(NPAR.EQ.0) GOTO 160
170 CONTINUE
AT THIS POINT THE CURRENT ITEM IS KNOWN TO HAVE BOTH INDEPENDANT
C
C
170 STOP
C
C

48100  DO 150 IORD=IORD+1
48120  CONTINUE
48140  CONTINUE
48160  THIS SECTION CALCULATES THE NET REQUIREMENTS FOR ITEM "IPROD".
48180  DO 50 I=2,IMRP
48200  NET(I)=SRECT(I)*INVROF(IPROD,I)-SRECT(I)
48220  CONTINUE
48240  CALL LOT(INVROF(IPROD,1),IPROD)
48260  CONTINUE
48280  THIS SECTION PLACES THE PLANNED ORDER RELEASE SCHEDULE FOR ITEM
48300  "IPROD" INTO THE PLANNED ORDER RELEASE STORAGE ARRAY "MRPP" FOR
48320  USE BY LOWER LEVEL ITEMS.
50100  DO 180 II=1,IMRP
50120  MRPP(IPROD,II)=PORDO(II)
50140  CONTINUE
50160  CONTINUE
50180  THIS SECTION DETERMINES IF A MATURE PLANNED ORDER RELEASE EXISTS
50200  FOR ITEM "IPROD" (I.E. IN THE ACTION BUCKET) IF A MATURE PLANNED
50220  ORDER RELEASE IS FOUND, THE ORDER IS PLACED IN THE RELEASE LIST.
50240  IF(PORDO(1).EQ.0) GOTO 220
50260  IQU=1
50280  DO 175 IDUE=1,IMRP
50300  IF(NET(IDUE).LT.INVROF(IPROD,5)) GOTO 196
50320  CONTINUE
50340  CONTINUE
50360  GOTO 220
50380  CONTINUE
50400  CALL ORDELE(IPROD,IPRT,IDUE)
50420  CONTINUE
50440  THIS SECTION PRINTS OUT THE PRODUCT EXPLOSION IF DESIRED. DUE TO
50460  SPACE ONLY THE FIRST TWELVE WEEKS ARE PRINTED.
50480  CONTINUE
50500  IF(WK.EQ.IPRT) GOTO 230
50520  WRITE(3,999)
50540  FORM=1,999
50560  WRITE(3,300) IPRD(IPROD)
50580  CALL SRECT(IPROD,1),INVROF(IPROD,2)
50600  L17,4X,"ALLOCATED INVENTORY","1",I
50620  UNALLOCATED INVENTORY","Z","1",I
50640  L17,4X,"LOT SIZE RULE","Z","1",I
50660  ORD=3,301 (II=I)
50680  WRITE(3,301) (II,II=I)
50700  WRITE(3,301) (II,II=I)
50720  WRITE(3,301) (II,II=I)
50740  WRITE(3,301) (II,II=I)
50760  WRITE(3,301) (II,II=I)
50780  WRITE(3,301) (II,II=I)
50800  WRITE(3,301) (II,II=I)
50820  WRITE(3,301) (II,II=I)
50840  WRITE(3,301) (II,II=I)
50860  WRITE(3,301) (II,II=I)
50880  WRITE(3,301) (II,II=I)
50900  WRITE(3,301) (II,II=I)
50920  WRITE(3,301) (II,II=I)
50940  WRITE(3,301) (II,II=I)
50960  WRITE(3,301) (II,II=I)
50980  WRITE(3,301) (II,II=I)
60100  WRITE(3,301) (II,II=I)
60120  WRITE(3,301) (II,II=I)
60140  WRITE(3,301) (II,II=I)
60160  WRITE(3,301) (II,II=I)
60180  WRITE(3,301) (II,II=I)
60200  WRITE(3,301) (II,II=I)
60220  WRITE(3,301) (II,II=I)
60240  WRITE(3,301) (II,II=I)
60260  WRITE(3,301) (II,II=I)
60280  WRITE(3,301) (II,II=I)
60300  WRITE(3,301) (II,II=I)
60320  WRITE(3,301) (II,II=I)
60340  WRITE(3,301) (II,II=I)
60360  WRITE(3,301) (II,II=I)
60380  WRITE(3,301) (II,II=I)
60400  WRITE(3,301) (II,II=I)
60420  WRITE(3,301) (II,II=I)
60440  WRITE(3,301) (II,II=I)
60460  WRITE(3,301) (II,II=I)
60480  WRITE(3,301) (II,II=I)
60500  WRITE(3,301) (II,II=I)
60520  WRITE(3,301) (II,II=I)
60540  WRITE(3,301) (II,II=I)
60560  WRITE(3,301) (II,II=I)
60580  WRITE(3,301) (II,II=I)
60600  WRITE(3,301) (II,II=I)
60620  WRITE(3,301) (II,II=I)
60640  WRITE(3,301) (II,II=I)
60660  WRITE(3,301) (II,II=I)
60680  WRITE(3,301) (II,II=I)
60700  WRITE(3,301) (II,II=I)
60720  WRITE(3,301) (II,II=I)
60740  WRITE(3,301) (II,II=I)
60760  WRITE(3,301) (II,II=I)
60780  WRITE(3,301) (II,II=I)
60800  WRITE(3,301) (II,II=I)
60820  WRITE(3,301) (II,II=I)
60840  WRITE(3,301) (II,II=I)
60860  WRITE(3,301) (II,II=I)
60880  WRITE(3,301) (II,II=I)
60900  WRITE(3,301) (II,II=I)
60920  WRITE(3,301) (II,II=I)
60940  WRITE(3,301) (II,II=I)
60960  WRITE(3,301) (II,II=I)
60980  WRITE(3,301) (II,II=I)
70100  WRITE(3,301) (II,II=I)
54000  250 CONTINUE 
54200  RETURN 
54300  260 WRITE(3,1000) 
54400  1000 FORMAT(" ERROR IN HRP:" TOO MANY ORDERS") 
54500  STOP 
54600  270 WRITE(3,1001) 
54700  1001 FORMAT(" HRP:" ORDER RELEASE ERROR") 
54800  STOP 
54900  END 
55000  SUBROUTINE ORDER (IPROD, ISIZE, IOWE) 
55100  C 
55200  C 
55300  C 
55400  COMMON /TIME/CLOCK, DTIME, PTIME, IDAY, IRUN, INEEK, IRCLEAR, NOAY, NSTOP, 
55500  1NWE IX, 1RRUNS, SDDAY, SVAL, 
55600  COMMON /PROD/ INROD(200,7), INWROD(200,15), IROUT(993), IROUT(993,5) 
55700  1NRONT(993,2), IROUT(993,2), VALEU(200,2), ISTAT(5,2,5,4), 
55800  2A STAT(5,2,4), ISTAT(5,2,200), 1STATL(5,2,9,200), ISTATL(6,2,5,200) 
55900  COMMON /PROD2/ DJF(20,4), IDEX(20,5), IDPSR(20,52), IDFSR(20,3), NFD, 
56000  1B(200), CARRY, IPRD, 1PRD, 1PRD, 1PRD, 1PRD, 1PRD, 1PRD, 1PRD, 1PRD, 
56100  2C(200), 2D(200), 2E(200), 2F(200), 2G(200), 2H(200) 
56200  COMMON /SHOP/ 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 
56300  1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 
56400  1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 
56500  1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 
56600  1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 
56700  1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 
56800  1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 
56900  1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 1MDP(1L,10), 
57000  IF(ISIZE.LT.0) WRITE(3,9000) 
57100  9000 FORMAT(" ERROR IN ORDER") 
57200  IF(INROD(IPROD,11).GT.0) INWROD(IPROD,11)=NOAY 
57300  ISTAT(L,L,IPROD)=ISTAT(L,L,IPROD)+1 
57400  UPOR(IPROD)=ISIZE 
57500  CALL CDAT2(UPOR(IPROD),CLOCK,OSTAT(1,L,IPROD)) 
57600  C 
57700  SETUP BLOGS...... 
57800  C 
57900  C 
58000  IF(IPROD.LT.1) RETURN 
58100  IF(IPROD.GT.200) RETURN 
58200  IF(IPROD.GT.3) I error=1 
58300  C 
58400  IF(DIFF.LT.0.0) DIFF=0.0 
58500  CALL CDAT2(DIFF,CLOCK,OSTAT(1,L,IPROD)) 
58600  195 CONTINUE 
58700  195 ICNT=ICNT+1 
58800  C 
58900  C 
59000  C 
59100  C 
59200  C 
59300  C 
59400  C 
59500  C 
59600  C 
59700  C 
59800  C 
59900  C 
60000  IF(NAVAIL.GT.2) GOTO 250
INDEX(HDATA(1,1))=0
CALL SSTORE(*SAVE*,*PORD,*AX,2)
RETURN

250 WRITE(1,1000)
1000 FORMAT('ERROR IN ORDERING TOO MANY OPEN ORDERS')
STOP
END

SUBROUTINE PSTAT1(XX,LAB,IPRTN,IPRT)

THIS SUBROUTINE Calculates the observational statistics from
the data stored in the "XX" array (current statistics array).

COMMON /BOTT3/ BORD(200),TLSTD(10),TABALD(10),TTVAL(7),QUEUE(10),
LATN(200)
COMMON /BOTT2/ IFLAG(7),JFLAG(5),KFLAG,IDEPT,YGR?,IIPROD,AXLOAD(3)
DIMENSION XX(1),LAB(1)
BVAL=1.0E-10

CALCULATE STATISTICS.

QBS=XX(3)

IF(QBS.NE.0.0) GOTO 100

AVE=SUM/3

IF(QBS.LT.1.0) GOTO 200

STD=SQRT((SUM-(SUM*SUM/3))/(QBS-1.0))

GOTO 300

ST0=0.0

STD=STD/ST0(QBS)

1

WRITE(3,301) (LAB(I),I=1,7),AVE,STD,STM,XX(4),1

901 FORMAT(5X,24X,6(7X,F3.3))

IF(JFLAG(5).EQ.1) TLSTD(IDEPT)=STD

IF(JFLAG(5).EQ.1) TABALD(IDEPT)=AVE

IF(JFLAG(1).EQ.1) TTVAL(1)=STD

IF(JFLAG(2).EQ.1) TTVAL(2)=STD

IF(JFLAG(3).EQ.1) TTVAL(3)=STD

IF(JFLAG(4).EQ.1) TTVAL(4)=STD

IF(JFLAG(5).EQ.1) TTVAL(5)=STD+AVE

UPDATE SUMMARY COLLECTORS.

IF(IPRTN.EQ.0) GOTO 400

XX(5)=XX(5)+XX(1)

XX(7)=XX(7)+XX(2)

XX(9)=XX(9)+XX(3)

IF(XX(3)+XX(4)) XX(9)=XX(4)

IF(XX(10)-LT.XX(5)) XX(10)=XX(5)

REINITIALIZE CURRENT COLLECTORS.

400 XX(1)=0.0

XX(2)=0.0

XX(3)=0.0

XX(4)=37.0
C THIS SUBROUTINE CALCULATES THE TIME-WEIGHTED STATISTICS FROM THE DATA STORED IN THE XX ARRAY (CURRENT STATISTICS ARRAY).
C
AREA = XX(2) + (XX(1) * (CLOCK-XX(4)))
AVE = (XX(1) + XX(3)) * (CLOCK-XX(4))
AVE = AREA / BASE
STD = (AVE / BASE - AVE) * AVE
STD = SIGN(STD) * ABS(STD)
IF (IPNRT.EQ.1) WRITE(3, 900) (LAB(I), I=1, 2), AVE, STD, XX(5), XX(6)
900 FORMAT(5, 2X, 2(5X, F10.2, 1X, "N/A", 5X, "F10.2", 5X, "F10.2", 11X, "N/A")
IF (IFLAG(1).EQ.1) TIVAL(5) = AVE
IF (IFLAG(2).EQ.1) TIVAL(7) = AVE
IF (IFLAG(3).EQ.1) BORD(IIPRD0) = AVE
IF (IFLAG(4).EQ.1) QUEU(EQPR) = AVE
ATNY(IIPRD0) = AVE
C UPDATE SUMMARY COLLECTORS.
C
IF (IPUTOT.EQ.0) GOTO 100
XX(7) = XX(1)
XX(8) = XX(3) + AREA
XX(9) = XX(7) + SS
XX(10) = CLOCK
IF (XX(11) > XX(5)) XX(11) = XX(3)
IF (XX(12) < XX(6)) XX(12) = XX(6)
C CLEAR OUT CURRENT COLLECTORS.
C
100 XX(2) = 0.0
XX(3) = 0.0
XX(4) = CLOCK
XX(5) = XX(1)
XX(6) = XX(1)
RETURN
C
C THIS SUBROUTINE PLACES THE RELEASED WORKER OR MACHINE BACK INTO THE PROPER LIST.
C
DIMENSION MM(1), NN(5, 1)
LAST = MM(4, MPRR)
NEXT = MM(5, MPRR)
C PUT WORKER(MACHINE) AT HEAD OF AVAILABLE LIST.
C
NN(4, MPRR) = 0
NN(5, MPRR) = NN(2)
34100 C PRINT ITEM HEADERS.
34200 C
34300 C IF(IPRMT.EQ.1) WRITE(3,3000) IIPROD,INVRF(IIIPROD,1),30(IIPROD),
34400 C INVRF(IIIPROD,2),TEMP1(IIIPROD),INVRF(IIIPROD,4),TEMP2(IIIPROD),
34500 C 2INVRF(IIIPROD,9)
34600 C 3000 FORMAT(//,ITEM,':','SUMMARY',//,
34700 C 1' CURRENT UNALLOCATED INVENTORY'-Z',I9,5X,
34800 C 2' CURRENT BACKORDERS'-Z',F9.0,
34900 C 3' CURRENT ALLOCATED INVENTORY'-Z',I9,5X,
35000 C 4' CURRENT BACKLOG(TOTAL)'-Z',F9.0,
35100 C 5' CURRENT ON-ORDER QUANTITY'-Z',I9,5X,
35200 C 6' CURRENT UNRELEASED ORDERS'-Z',F9.0,
35300 C 7' NUMBER OF OPEN ORDERS'-Z',I9)
35400 C
35500 C CALCULATE ALL OBSERVATIONAL STATISTICS FOR ITEM "IIPROD"
35600 C
35700 C IF(IPRMNT.EQ.1) WRITE(3,801) IIPROD
35800 C 801 FORMAT(//,45X,'ALL TIMES IN STANDARD DAYS',//,7X,'ITEM',//,
35900 C 1113,1IX,'MEAN',7X,'STD. DEV.',7X,'S.D.',7X,'MEAN',7X,'MINIMUM',7X,
36000 C 2'MAXIMUM',7X,'A OF 385.')
36100 C 802 FORMAT(5X,2A4,2X,'O OF VALUES RECORDED')
36200 C 803 FORMAT(5X,2A4,6X,'7X,FB.2')
36300 C
36400 C CALCULATE OBSERVATIONAL STATISTICS FOR ITEM "IIPROD".
36500 C
36600 C DO 120 II=1,9
36700 C IF(IIPROD.GT.WFG.AND.II.EQ.2) GOTO 120
36800 C IF(IIPROD.GT.WFG.AND.II.EQ.5) GOTO 120
36900 C IF(IIPROD.GT.WFG.AND.II.EQ.9) GOTO 120
37000 C CALL PSTATI(OSTATI(1,ICODE,II,IIPROD),LAB1(1,II),IPRM,1)
37100 C 120 CONTINUE
37200 C
37300 C CALCULATE AND PRINT OUT TIME-PERSISTENT STATISTICS.
37400 C
37500 C DO 130 II=1,5
37600 C IF(II.EQ.4) IFLAG(3)=1
37700 C IF(II.EQ.1.AND.IIPROD.LE.WFG) IFLAG(7)=1
37800 C CALL PSTAT2(OSTAT2(1,ICODE,II,IIPROD),CLOCK,TBASE,LAB2(1,II),
37900 C 1 IPRM,1)
38000 C IFLAG(3)=0
38100 C IFLAG(7)=0
38200 C 130 CONTINUE
38300 C
38400 C PRINT ORDER RELEASE STATISTICS.
38500 C
38600 C IF(IPRMNT.EQ.1) WRITE(3,810)
38700 C 810 FORMAT(//,3X,'ORDER RELEASE STATISTICS FOR DELAYED/REDUCED ORDERS')
38800 C
38900 C IF(IPRMNT.EQ.2) WRITE(3,811) (ISTAT(JJ,ICODE,IIPROD),JJ=1,4)
39000 C 811 FORMAT(//,'ATTEMPTED ORDER RELEASES',1X,'RELEASED ORDER QUANTITY=',I4,
39100 C 1,'ORDERS RELEASED WITH REDUCED ORDER QUANTITY=',I4,
39200 C 2,'ORDERS NOT RELEASED',I4)
39300 C
39400 C RESET ORDER RELEASE STATISTICS.
39500 C
39600 C DO 210 JJ=1,4
39700 C ISTAT(JJ,ICODE,IIPROD)=ISTAT(JJ,2,IIPROD)+ISTAT(JJ,1,IIPROD)
39800 C 210 CONTINUE
39900 C IF(IWEEK.NE.WCLEAR) GOTO 220
40000 C DO 215 JJ=1,5
ISTAT(I1,2,1IPROD)=0
90700 215 CONTINUE
90900 220 IF(1IPROD,4,1XG) GOTO 240
91400 IF(1IPROD(1IPROD,3),EQ,0) GOTO 240
90600 C PRINT COMPONENT SUMMARY REPORT.
90600 C
90660 IF(1IPRT,EQ,1) WRITE(3,812)
90900 812 FORMAT(5X,"COMPONENT SHORTAGE SUMMARY",/,,3X,"COMPONENT #",
91000 13X,"SHORTAGES","3X,"CRITICAL")
91100 IFRST=INDEX(IIPROD,4)
91200 ILast=INDEX(IIPROD,3)+IFRST-1
91300 INCL=(2*ICODE)+1
91400 IND2=IND1+1
91500 DO 230 II=IFRST,ILAST
91600 IF(1IPRT,EQ,1) WRITE(3,913) MBILL(II,1),MBILL(II,INCL),
91700 1 MBILL(II,IND2)
91800 813 FORMAT(5X,15,8X,15,5X,15)
91900 MBILL(I1,5)=MBILL(I1,5)+MBILL(I1,3)
92000 MBILL(I1,6)=MBILL(I1,6)+MBILL(I1,4)
92100 MBILL(I1,3)=0
92200 MBILL(I1,4)=0
92300 IF(IWEXK,NICLEAR) GOTO 230
92400 MBILL(I1,5)=0
92500 MBILL(I1,6)=0
92600 230 CONTINUE
92700 240 CONTINUE
92800 1PRNT=1IPRT
92900 C THIS SECTION PRINTS OUT THE AGGREGATED INVENTORY
93000 C STATISTICS.
93000 C
93300 IF(1IPRT,EQ,1) WRITE(3,316)
93400 316 FORMAT(1X,15,"AGGREGATE INVENTORY AND"/
93500 2, "ORDER STATISTICS BY PRODUCT")
93600 2 CLAS S///)
93700 DO 290 KK=1,4
93800 IF(1IPRT,EQ,1) WRITE(3,317) (LAB3(JJ,KK),JJ=1,5)
93900 317 FORMAT(15X,"ALL TIMES IN STANDARD DAYS",/,,1X,
94000 15A4,6X,"MEAN",3X,"STD.DEV.",7X,
94100 250 OF MEAN",7X,"MINIMUM",7X,"MAXIMUM",7X,"% OF CDS.")
94200 DO 280 II=1,5
94300 IF(KK,EQ,3,AND,II,EQ,2) GOTO 285
94400 CALL PSTAT(I1STAT1(I1,ICODE,KK),L431(I1,II),1PRNT,1)
94500 280 CONTINUE
94600 290 CONTINUE
94700 C CALCULATE AVERAGE INVENTORY IN DOLLARS.
94800 C
94900 IF(KK,EQ,1) IFLAG(1)=1
95000 IF(KK,EQ,3) IFLAG(2)=1
95100 CALL PSTAT(4STAT1(I1,ICODE,KK),CLOCK,IPBAS,E,L431(I1,II),1PRNT,1)
95200 IFLAG(1)=3
95300 IFLAG(2)=0
95400 290 CONTINUE
95500 C PRINT OUT WORK-IN-PROCESS INVENTORY STATISTICS.
95600 C
95800 IF(1IPRT,EQ,1) WRITE(3,318)
95900 318 FORMAT(1X,"WORK-IN-PROCESS INV.",3X,"MEAN",8X,"STD.DEV.",/
96000 15X,"50 OF MEAN",5X,"MINIMUM",7X,"MAXIMUM",7X,"% OF CDS.")
CALL PSTAT(1IPS(1,ICODE),CLACK,EBASE,LAB1(1,11),IPRNT,1)
98200  IF(IPRNT.EQ.1) WRITE(3,331)
98300  331 FORMAT('\\/\\/ QUERY LOAD STATISTICS FOR ID1AL SHIP\\/\\/','
98400  'L,24X,'\"MEAN\"','8X,'\"STO.DEV.\"','8X,'
98500  '2\"SD OF MEAN\"','8X,'\"MINIMUM\"','8X,'\"MAXIMUM\"','8X',\"# OF OBS\")
98600  DO 410 IT=1,8
98700  IF(II.EQ.1) JFLAG(1)=1
98800  IF(II.EQ.2) JFLAG(2)=1
98900  IF(II.EQ.3) JFLAG(3)=1
99000  IF(II.EQ.4) JFLAG(4)=1
99100  IF(II.EQ.5) JFLAG(5)=1
99200  CALL PSTAT(QSTAT1(1,ICODE,II,NGRP),L194(1,11),IPRNT,1)
99300  DO 408 KJ=1,5
99400  JFLAG(KJ)=3
99500  408 CONTINUE
99600  410 CONTINUE
99700  C CLEAR OUT SUMMARY COLLECTORS IF INEEK EQUALS NCLEAR.
99800  C
99900  IF(INEEK.NE.NCLEAR) RETURN
10000  DO 450 J=1,9
10010  QSTAT1(1,2,J,NGRP)=0.0
10020  QSTAT1(2,2,J,NGRP)=0.0
10030  QSTAT3(J,2,J,NGRP)=0.0
10040  QSTAT3(J,4,J,NGRP)=BVAL
10050  QSTAT1(J,5,J,NGRP)=-BVAL
10060  450 CONTINUE
10070  DO 310 JPROD=1,NPROD
10080  IND=-4
10090  DO 310 JJ=1,2
10100  DO 300 II=1,9
10110  QSTAT1(1,II,II,JPROD)=0.0
10120  QSTAT1(2,II,II,JPROD)=0.0
10130  QSTAT3(JJ,II,J,IPROD)=0.0
10140  QSTAT3(JJ,4,II,JPROD)=BVAL
10150  300 CONTINUE
10160  DO 305 JJ=1,5
10170  QSTAT1(1,2,II,JPROD)=QSTAT2(1,1,JJ,JPROD)
00100    OSTAT2(1,1, JJ, IPROD) = J.0
00200    OSTAT2(1,2, JJ, IPROD) = J.0
00300    OSTAT2(1,3, JJ, IPROD) = CLOCK
00400    OSTAT2(1,4, JJ, IPROD) = OSTAT2(1,1, JJ, IPROD)
00500    OSTAT2(2,1, JJ, IPROD) = OSTAT2(2,2, JJ, IPROD)
00600    305 CONTINUE
00700    310 CONTINUE
00800    DO 330 II = 1, 4
00900    DO 320 JJ = 1, 5
01000    ASTATI(1,1, JJ, II) = 0
01100    ASTATI(2,2, JJ, II) = 0
01200    ASTATI(3,3, JJ, II) = 0
01300    ASTATI(4,4, JJ, II) = 0
01400    ASTATI(5,5, JJ, II) = 0
01500    320 CONTINUE
01600    ASTATI(1,2, JJ, II) = 0
01700    ASTATI(3,2, JJ, II) = 0
01800    ASTATI(5,2, JJ, II) = 0
01900    ASTATI(2,2, JJ, II) = 0
02000    330 CONTINUE
02100    WIPS(1,2) = 0
02200    WIPS(3,2) = 0
02300    WIPS(5,2) = 0
02400    WIPS(6,2) = 0
02500    RETURN
02600    END
02700    SUBROUTINE REPORT (ICODE, IPRINT)
02800    C
02900    C THIS SUBROUTINE CALCULATES AND PRINTS OUT OPERATIONAL (I.E. SHOP)
03000    C STATISTICS. THIS SUBROUTINE MUST BE CALLED EVERY WEEK TO UPDATE
03100    C EACH STATISTIC. A REPORT IS GENERATED IF THE VARIABLE "IPRINT"
03200    C EQUALS ONE (1). IF "IPRINT" EQUALS ZERO (0), NO REPORT IS GENERATED
03300    C BUT THE STATISTICS ARE UPDATED. THE REPORTS GENERATED HAVE THREE (3)
03400    C DIFFERENT OBSERVATION PERIODS: 1 (1) ONE WEEK; 2) "NOWEEK" WEEKS
03500    C (I.E. AN ENTIRE RUN); AND 3) SUMMARY OF ALL WEEKS (EXCEPT THE
03600    C INITIALIZATION PERIOD).
03700    C
03800    C
03900    COMMON /TIKEL,CLOCK,TIME,PHIE,DAY,IRUN,WEK,NCLEAR,NOAY,NSTOP,
04000    1NEEK,WRONG,STODS,IVAL
04100    COMMON /P3D11/ IVP2(200,7), ITMOD(200,15), IMOU(993), IMR(993,9)
04200    1NRO(993,2), IDROUT(993,2), IDPVAL(200,2), ISTATI(5,2,5,4)
04300    2STATI(5,2,4), ISTATI(5,2,200), ISTATI(5,2,9,200), ISTATI(5,2,5,200)
04400    COMMON /P3D12/ BPNR(20,4), IIND(20,5), IPROE(20,5), INPN(20,3), IFUG,
04500    1BQ(200), CARC, HPS, 1F1, 1F2, 1F3, 1F4, 1F5, WPS(5,2), 1WPS
04600    2BLOC(200), IPEQ(200)
04700    COMMON /SCRP/ HIP(W,11,10), HIP(12,10), HIP(15,100)
04800    1MEN(5,100), HDEP, HREP, SMACK(4,100,3), JDATA(5,10)
04900    2JQUO(4,10,3), ISTATI(5,10,3), ISTATI(5,2,9,11), ISTATI(5,2,3,10)
05000    COMMON /ORDDR/ NORDER, INDEX, IORDER(393,3), IORDER(393,3), NHAVAIL,
05100    1MGRD(32), NEOM, HREP, YMAHR, ORDER(393,9)
05200    COMMON /MRPI/ HBPIL(993,9), HPS(20,32), HREP(200,52), HBRIL(993,9)
05300    1MRP
05400    COMMON /CWEV1/ ICST(13)
05500    COMMON /JRTI/ SSHA(10), ICODE, IX
05600    COMMON /JRT2/ JFLAG(7), JFLAG(8), JFLAG(9), JCODE, JREP, JPR, JPR(3), AXLDAD(3)
05700    DIMENSION LAB(2,2), LAB(2,3), LAB(4,3), LAB(4,2,10)
05800    DATA LAB(3,2), LAB(2,2), LAB(2,3), LAB(4,3), LAB(4,2,10)
05900    1, "ST7", "JPO", "UAVX", "JPO", "TOT", "JPO", "ABU4", "L4QO"/
06000    DATA LAB(2,2) = OPO, JPO, TOT, HOP"
I'D "','SIMILLA'M','R" "/
06200 C PRINT OUT REPORT HEADER.
06400 C IF(IPRINT.EQ.1) WRITE(3,900) (LAB3(KK,ICODE),KK=1,4),IEXK
06500 800 FORMAT('"1","3","4","OPERATIONS REPORT",/"
06600 1,5X,,'3EXK'='1',1X,///)
06800 C INITIALIZE MACHINE GROUP AND MACHINE PRINTERS.
07000 C MCH=0
07100 C MGRP=0
07300 C CALCULATE THE PROPER NUMBER OF WEEKS AND TIME BASE ON WHICH
07500 C TO BASE STATISTICS.
07600 C ATIME=(STODAY*5.0)/50.0
07800 NWEEKS=NWEEK
07900 IF(NWEEK.EQ.NCLEAR) NWEEKS=NCLEAR
08000 IF(ICODE.EQ.3) NWEEKS=(NWEEK-NCLEAR)
08100 IF(ICODE.EQ.1) ATIME=ATIME*NWEEKS
08200 C INITIALIZE SHOPWIDE STATISTICS
08400 C TALSUM=0.0
08500 TCLSUM=0.0
08600 TTLSUM=0.0
08700 TABSUM=0.0
08900 TUSUM=0.0
09000 TATIME=0.0
09100 C SETUP LOOP FOR EACH DEPARTMENT
09200 C DO 150 IDEPT=1,NDEPT
09300 C IF(IPRINT.EQ.1) WRITE(3,803) IDEPT
09400 803 FORMAT('IX""DEPARTMENT""IX,""MACHINE GROUP
09500 1 AND LABOR SUMMARY",///)
09600 C INITIALIZE DEPARTMENTAL COLLECTORS.
09900 C OSSUM=0.0
10100 C DASSUM=0.0
10200 C DRSUM=0.0
10400 C DRSUM=0.0
10500 C DUSUM=0.0
10600 C DTIME=0.0
10700 C SETUP LOOP FOR EACH MACHINE GROUP IN DEPARTMENT "IDEPT".
10800 C NVAL=NDEPT(3,IDEPT)
10900 C DO 140 IGRP=1,NVAL
11000 C WRITE HEADER FOR MACHINE GROUP UTILIZATION STATISTICS AND
11100 C INITIALIZE MACHINE GROUP COLLECTORS.
11200 C IF(IPRINT.EQ.1) WRITE(3,104) IGRP
11400 104 FORMAT(4"UTILIZATION STATISTICS FOR MACHINE GROUP ",13,///,3X,
11500 1"TIME IN HOURS",3X,TIME IN PERCENT",///,1X,
11600 2"ACHIEVABLE",3X,SETUP TIME",5X,RUN TIME",3X,
11700 3"TOTAL TIME",3X,AVALIABLE",3X,"SETUP TIME",2X,
C THIS SECTION PROCESSES EACH MACHINE WITHIN THE MACHINE GROUP
C AND CALCULATES INDIVIDUAL USAGES. IF THE MACHINE IS CURRENTLY
C IN USE, THE PROCESSING TIME REMAINING WHICH IS ASSOCIATED WITH
C THE UNFINISHED ORDER IS DETERMINED AND THE USAGE ADJUSTED.

11700  MVAL = MCHRP (1, MGRP)
11800  SATime = MVAL * ATIME
11900  DO 130 IF = 1, MVAL
12000  MCH = MCH + 1
12100  DELTA = 0.0
12200  PROVITY = MCH (1, MCH (3, MCH))/180.0
12300  STIME = SMACH (1, MCH, ICODE)
12400  ATIME = SMACH (2, MCH, ICODE)
12500  RTIME = SMACH (3, MCH, ICODE)
12600  ARTIME = SMACH (4, MCH, ICODE)
12700  SMACH (1, MCH, ICODE) = 0.0
12800  SMACH (2, MCH, ICODE) = 0.0
12900  SMACH (3, MCH, ICODE) = 0.0
13000  SMACH (4, MCH, ICODE) = 0.0
13100  IF (MCH (1, MCH) .EQ. 0) GOTO 120
13200  DELTA = ORDER (MACH (2, MCH), 1) - CLOCK
13300  CSUN = CSUN + DELTA / PROVITY
13400  CASUM = CASUM + DELTA
13500  IF (ICODE .NE. 1) GOTO 120
13600  RუRUN = ORDER (MACH (2, MCH), 1)
13700  IF (RUN .LT. DELTA) GOTO 110
13800  C
13900  C DIFFERENCE IS DUE ONLY TO REMAINING RUN TIME.
14000  C
14100  SMACH (3, MCH, 1) = DELTA / PROVITY
14200  RTIME = RTIME - SMACH (3, MCH, 1)
14300  SMACH (4, MCH, 1) = DELTA
14400  ARTIME = ARTIME - DELTA
14500  GOTO 120
14600  C
14700  C DIFFERENCE IS DUE TO BOTH REMAINING SETUP AND RUN TIME
14800  C
14900  Sсет = DELTA - RUN
15000  SMACH (1, MCH, 1) = Sсет / PROVITY
15100  STIME = STIME - SMACH (1, MCH, 1)
15200  SMACH (2, MCH, 1) = Sсет
15300  ATIME = ATIME - Sсет
15400  SMACH (3, MCH, 1) = RUN / PROVITY
15500  RTIME = RTIME - SMACH (3, MCH, 1)
15600  SMACH (4, MCH, 1) = RUN
15700  ARTIME = ARTIME - RUN
15800  C
15900  C CONVERT TIMES INTO HOURS AND PERCENTAGES.
16000  C
18100  120 IF (ICODE.EQ.3) GOTO 125
18200  SMACH(1,4CH,ICODE+1)=SMACH(1,4CH,ICODE+1)+STIME
18300  SMACH(2,4CH,ICODE+1)=SMACH(2,4CH,ICODE+1)+STIME
18400  SMACH(3,4CH,ICODE+1)=SMACH(3,4CH,ICODE+1)+ARTIME
18500  SMACH(4,4CH,ICODE+1)=SMACH(4,4CH,ICODE+1)+ARTIME
18600  125 STIME=STIME/50.0
18700  ASTIME=ASTIME/50.0
18800  ARTIME=ARTIME/50.0
18900  UTIME=UTIME-ARTIME
19000  ASSUM=ASSUM+STIME
19100  RSUM=RSUM+ARTIME
19200  ARSUM=ARSUM+ARTIME
19300  RUSUM=RSUM+UTIME
19400  19600 PASET=(ASTIME/ARTIME)*100.
19700  PARUN=(ARTIME/ARTIME)*100.
19800  POWN=(UTIME/ARTIME)*100.
19900  DELTA=DELTA/50.
20000  IF (IPRINT.EQ.1) WRITE(3,805) II,ASTIME,ARTIME,UTIME,ATIME,PASET,
20100  IPARUN,POWN,PACH(1,4CH),DELTA
20300  1S5.2,5X,F9.2,5X,1S5.2,5X,1S5.2,5X,1S5.2,5X,1S5.2,5X,1S5.2,5X,
20400  IF (WEEK,NE,NCLEAR) GOTO 130
20500  SMACH(1,4CH,3)=0.0
20600  SMACH(2,4CH,3)=0.0
20700  SMACH(3,4CH,3)=0.0
20800  SMACH(4,4CH,3)=0.0
20900  CONTINUE
21000  DSSYM=DSSYM+SSYM
21100  QSSYM=QSSYM+ASSYM
21200  QRSYM=QRSYM+ARSYM
21300  QARSYM=QARSYM+ARSYM
21400  DUSYM=DUSYM+USYM
21500  TUSYM=TUSYM+USYM
21600  PASET=(ASSYM/ARTIME)*100.
21700  PARSUN=(ARSUM/ARTIME)*100.
21800  POWN=(USYM/ARTIME)*100.
21900  CSD=CSYM/50.
22000  CASYM=CASYM/50.
22100  IF (IPRINT.EQ.1) WRITE(3,806) ASSYM,ARSYM,USYM,ASTIME,PASET,
22200  IPARUN,POWN,PACH(1,4CH)
22400  1S5.2,5X,F9.2,5X,1S5.2,5X,1S5.2,5X,1S5.2,5X,1S5.2,5X,
22500  C  THIS SECTION PRINTS OUT QUEUE RELATED DATA.
22600  C
22700  C
22800  IF (IPRINT.EQ.1) WRITE(3,807) IGRP
22900  807 FORMAT(13/"LOAD DATA FOR MACHINE GROUP ",I3,/ 
23000  1S5X,"TIME IN HOURS",/34X,"OF JOBS",6X,
23100  1S5X,"TOTAL TIME",/5X,"TOTAL TIME")
23200  VAL1=JOS(1,4GRP,ICODE)/50.
23300  VAL2=JOS(2,4GRP,ICODE)/50.
23400  TOT=VAL1+VAL2
23500  IF (IPRINT.EQ.1) WRITE(3,308) IGRP,ICODE,VAL1,VAL2,TOT
23600  308 FORMAT(2X,"BEGINNING QUEUE",/3X,I3,7X,3(F13.2,5X))
23700  VAL1=JOS(3,4GRP,ICODE)/50.
23800  VAL2=JOS(4,4GRP,ICODE)/50.
23900  TOT=VAL1+VAL2
24000  IF (IPRINT.EQ.1) WRITE(3,309) IGRP,ICODE,VAL1,VAL2,TOT
24100 809 FORMAT(* ARRIVALS *,18X,5S,7X,3(F10.2,5X))
24200 IF(ICODE.EQ.1) CALL COUNAT(LOT,ISTAT(1,1,2,74R))
24300 TALSUM=TALSUM+TOT
24400 SAVE=TALSUM+SUM
24500 IF(IPRN.EQ.1) WRITE(3,810) VSTAT(3,4GRP,ICODE),SSM,RSUM,SAVE
24600 810 FORMAT(* COMPLETIONS(STANDARD) *,11X,5S,7X,3(F10.2,5X))
24700 IF(ICODE.EQ.1) CALL COUTAT(SAVE,OSTAT(1,1,3,74R))
24800 TCSUM=TCSUM+SAVE
24900 TOT=TCSUM+SUM
25000 IF(IPRN.EQ.1) WRITE(3,811) VSTAT(3,4GRP,ICODE),ASSUM,ARSUM,TOT
25100 811 FORMAT(* COMPLETIONS(Actual) *,11X,5S,7X,3(F10.2,5X))
25200 IVAL=QSTAT(1,1,1,74R)
25300 VALI=QDATA(1,4GRP)/50.
25400 VAL2=QDATA(2,4GRP)/50.
25500 TOT=IVAL+VAL2
25600 IF(IPRN.EQ.1) WRITE(3,812) IVAL,IVAL,IVAL,TOT,
25700 812 FORMAT(* ENDING QUEUE *,11X,5S,7X,3(F10.2,5X))
25800 SAVE=SAVE+TOT+CSUM
25900 IF(ICODE.EQ.1) CALL COUTAT(SAVE,OSTAT(1,1,4,74R))
26000 TCSUM=TCSUM+SAVE
26100 ASAVE=ABS(SAVE-SSAVE(4GRP))
26200 IF(ICODE.EQ.1) CALL COUTAT(ASAVE,OSTAT(1,1,3,74R))
26300 ABSUM=ABS1M+ASAVE
26400 IF(ICODE.EQ.1) SSAT(4GRP)=SAVE
26500 1311 FORMAT(* UPDATE COLLECTOR VARIABLES)
26600 C
26700 C
26800 IF(ICODE.EQ.3) GOTO 131
26900 QJO(3,4GRP,ICODE+1)=QJO(3,4GRP,ICODE+1)+JJO(3,4GRP,ICODE)
27000 QJO(4,4GRP,ICODE+1)=QJO(4,4GRP,ICODE+1)+JJO(4,4GRP,ICODE)
27100 QJO(1,4GRP,ICODE)=QDATA(1,4GRP)
27200 QJO(2,4GRP,ICODE)=QDATA(2,4GRP)
27300 QJO(3,4GRP,ICODE)=0.0
27400 QJO(4,4GRP,ICODE)=0.0
27500 MSTAT(1,4GRP,ICODE+1)=MSTAT(1,4GRP,ICODE+1)+MSTAT(1,4GRP,ICODE)
27600 MSTAT(2,4GRP,ICODE+1)=MSTAT(2,4GRP,ICODE+1)+MSTAT(2,4GRP,ICODE)
27700 MSTAT(3,4GRP,ICODE)=IVAL
27800 MSTAT(4,4GRP,ICODE)=0
27900 MSTAT(5,4GRP,ICODE)=0
28000 131 IF(INWK.EQ.NCLEAR) GOTO 139
28100 QJO(1,4GRP,3)=QDATA(1,4GRP)
28200 QJO(2,4GRP,3)=QDATA(2,4GRP)
28300 QJO(3,4GRP,3)=0.0
28400 QJO(4,4GRP,3)=0.0
28500 MSTAT(1,4GRP,3)=IVAL
28600 MSTAT(2,4GRP,3)=0
28700 MSTAT(3,4GRP,3)=0
28800 139 DATIME=DATIME+TATIME
28900 C
29000 C THIS SECTION CALCULATES AND PRINTS OUT THE QUEUE STATISTICS
29100 C FOR THE CURRENT MACHINE GROUP. THIS SECTION IS NOT USED
29200 C FOR WEEKLY OPERATIONS REPORTS.
29300 C
29400 IF(ICODE.EQ.1) GOTO 140
29500 JSTAT=ICODE-1
29600 IF(IPRN.EQ.1) WRITE(3,914) IGRP
29700 914 FORMAT(* QUEUES STATISTICS FOR MACHINE GROUP *,11/
29800 12X,"MAX","MIN","MEAN","STDEV","X","Y","Z")
29900 37X,"# OF Q2")
ATIME=ATIME*60.
CALCULATE/PRINT OUT TIME-PERSISTENT MACHINE GROUP STATISTICS.
DO 160 II=1,2
   IF(II.EQ.1) IFLAG(4)=1
   CALL PSTAT2(JSTAT2(I,JSTAT,II,MGRP),CLOCK,ATIME,LAB2(I,II),
   1   IPRTNT,1)
   IFLAG(4)=0
160 CONTINUE
CALCULATE/PRINT OUT OBSERVATIONAL MACHINE GROUP STATISTICS.
DO 170 II=1,8
   IF(II.EQ.4) IFLAG(5)=1
   IF(II.EQ.8) IFLAG(5)=1
   CALL PSTAT1(JSTAT1(I,JSTAT,II,MGRP),LAB1(I,II),IPRTNT,1)
   IFLAG(5)=0
   IFLAG(5)=0
170 CONTINUE
ATIME=ATIME/60.
THIS SECTION CLEARS OUT THE QUEUE RELATED STATISTICS
GENERATED DURING THE INITIALIZATION PERIOD.
IF(INDEX.NE.NCLEAR) GO TO 140
DO 200 II=1,8
   QSTAT1(1,2,II,MGRP)=0.0
   QSTAT1(2,2,II,MGRP)=0.0
   QSTAT1(3,2,II,MGRP)=0.0
   QSTAT1(4,2,II,MGRP)=0.0
   QSTAT1(5,2,II,MGRP)=CLOCK
   QSTAT1(6,2,II,MGRP)=QSTAT1(1,1,II,MGRP)
200 CONTINUE
   DO 210 II=1,3
   QSTAT2(1,2,II,MGRP)=QSTAT2(1,1,II,MGRP)
   QSTAT2(2,2,II,MGRP)=0.0
   QSTAT2(3,2,II,MGRP)=0.0
   QSTAT2(4,2,II,MGRP)=CLOCK
   QSTAT2(5,2,II,MGRP)=QSTAT2(1,1,II,MGRP)
210 CONTINUE
THIS SECTION CALCULATES AND PRINTS OUT THE LABOR HOURS
SUMMARY FOR THE CURRENT DEPARTMENT.
PASST=(OASU/ATIME)*100.
PA Run=(OARU/ATIME)*100.
PJW = (OSU/ATIME) * 100.
ATIME=ATIME+ATIME
IF(IPRTNT.EQ.1) WRITE(3,319) DEPT
817 FORMAT(I4, " LABOR USAGE FOR DEPARTMENT ",I1, //,2X,
1 CALL'S " ,I4, " PERCENT\%")
IF(IPRTNT.EQ.1) WRITE(3,320) DSSU, PASET
820 FORMAT(1X, " SETUP TIME ",4X, F9.2, 5X, F9.2)
IF(IPRTNT.EQ.1) WRITE(3,321) DARSU, PRUN
821 FORMAT(1X, " RUN TIME ",4X, F9.2, 5X, F9.2)
IF(IPRTNT.EQ.1) WRITE(3,322) DMSU, PDYN
822 FORMAT(1X, " DMSU\% TIME ",4X, F9.2, 5X, F9.2)
IF(IPRTNT.EQ.1) WRITE(3,323) DTIME
36100  823 FORMAT(3x,"TOTAL TIME ",4x,F8.2,5x,"100.00",//)
36150 CONTINUE
36200  PDWN=(CUST/STATTIME)*100.
36250  PUP=100.-PDWN
36300  IF(PRINT.EQ.1) WRITE(3,901) PUP,PDWN
36350  901 FORMAT(/,3x,"& UTIL.,",F6.2,3x,"& IDLE,",F5.2)
36400  IF( (CODE.EQ.1) ) RETURN
36450  CALL COATAI(TALSUM,OSTAT(1,1,2,NGRP))
36500  CALL COATAI(TALSUM,OSTAT(1,1,1,NGRP))
36550  CALL COATAI(TALSUM,OSTAT(1,1,4,NGRP))
36600  CALL COATAI(TALSUM,OSTAT(1,1,3,NGRP))
36650  RETURN
37000 END
37400 SUBROUTINE RMAH
37500 C THIS SUBROUTINE LOCATES ALL ORDERS FOR PURCHASED ITEMS THAT
37600 C ARE TO BE RECEIVED ON THE CURRENT DAY. ONCE THE ORDER IS
37700 C FOUND, THE "COMPLT" SUBROUTINE IS CALLED TO PROCESS THE ORDER.
37800 C
37900 COMMON /TIME1,CLOCK,TIME,PRINT,DATE,IRN,IRUN,IEEK,NCLEAR,NDAY,NSTEP,
38000   LNDAY,LLDAY,VAL,
38100 COMMON /INDEX3,INDEX,IBRE,IBER,IBER2,IBER3,IBER4,IBER5,IBER6,IBER7,
38200   IBER8,IBER9,IBER10,100,
38300 COMMON /INDEX4,INDEX4,INDEX5,
38400 COMMON /INDEX5,INDEX5,100,
38500 COMMON /INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
38600   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
38700   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
38800   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
38900   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
39000   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
39100   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
39200   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
39300   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
39400   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
39500   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
39600   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
39700   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
39800   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
39900   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
40000   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
40100   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
40200   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
40300   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
40400   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
40500   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
40600   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
40700   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
40800   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
40900   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
41000   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
41100   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
41200   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
41300   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
41400   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
41500   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
41600   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
41700   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
41800   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
41900   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
42000   INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,INDEX6,
42100        TLAST=10.0**20.0
42200        IFFST=IDEPT(3,IDEPT)
42300        ILAST=IFFST+IDEPT(8,IDEPT)-1
42400        DO 110 II=IFFST,ILAST
42500        IF(MGRP(II,II).EQ.0) GOTO 110
42600        IF(QSTAT2(1,1,1,II).EQ.0) GOTO 110
4270        IF(QSTAT(1,1,1,II).LT.VAL) GOTO 110
42800        IF(QSTAT2(1,1,1,II).EQ.VAL.AND.QDATA(3,II).GT.TLAST) GOTO 110
42900        TLAST=QDATA(3,II)
43000        VAL=QSTAT2(1,1,1,II)
43100        MGRP=II
43200        110 CONTINUE
43300        IF(MGRP.NE.0) CALL SERQ(MGRP,JQ0)
43400        RETURN
43500        C
43600        C SELECT MACHINE GROUP WITH LARGEST QUEUE (I.E. LONG WORK)
43700        C AND WITH AN AVAILABLE MACHINE.
43800        C
43900        C
44000        200 VAL=0.0
44100        TLAST=10.0**20.0
44200        IFFST=IDEPT(3,IDEPT)
44300        ILAST=IFFST+IDEPT(8,IDEPT)-1
44400        DO 210 II=IFFST,ILAST
44500        IF(MGRP(II,II).EQ.0) GOTO 210
44600        TTONE=QDATA(1,II)+QDATA(2,II)
44700        IF(TTONE.LE.0) GOTO 210
44800        IF(TTONE.LT.VAL) GOTO 210
44900        IF(TTONE.EQ.VAL.AND.QDATA(3,II).GT.TLAST) GOTO 210
45000        TLAST=QDATA(3,II)
45100        VAL=TTONE
45200        MGRP=II
45300        210 CONTINUE
45400        IF(MGRP.NE.0) CALL SERQ(MGRP,JQ0)
45500        RETURN
45600        END
45700        C
45800        C THIS ROUTINE ORDERS THE LIST BASED ON THE "IRNK" CELL
45900        C 
46000        C "IRDN", THE FORWARD POINTER TO NEXT CELL IS "IF", THE
46100        C BACKWARD POINTER TO LAST CELL IS "IB".
46200        C
46300        COMMON ORDRS, INDEX(993,5), IRDER(393,3), IRDERH(993,29), NAVAIL,
46400        INDEX(52), NEXTN, MPRG, WPRG, ORDER(993,5)
46500        LAST=0
46600        NEXT=NPRR
46700        C
46800        C IF NEXT = ZERO, ENTRY IS ENTRY IN LIST
46900        C
47000        IF(NEXT.EQ.0) GOTO 200
47100        C
47200        C CURRENT ENTRY IS PROMPTED IN LIST OR LAST IN LIST
47300        C
47400        100 IF(ORDER(NEXT,IRNK).GT.IRDERH(JOB,IRNK)) GOTO 200
47500        LAST=NEXT
47600        NEXT=INDEX(NEXT,IF)
47700        IF(NEXT.EQ.0) GOTO 100
47800        C
47900        C CURRENT ENTRY IS LAST ENTRY.
48000        C
43000 200 IF(LAST .GE. 0) NPTR=JOB
43100 C I.F(LAST .GE. 0) INDEX(LAST, IF)=JOB
43200 INDEX(JOB, IF)=LAST
43300 INDEX(JOB, IF)=NEXT
43400 IF(NEXT .NE. 0) INDEX(NEXT, IB)=JOB
43500 RETURN
43600 END
43700 SUBROUTINE SORTO(JOB, NPTR, TIME, IRNK)
49000 C THIS SUBROUTINE RANKS ENTRIES IN THE ORDER LISTS. THE
49100 C ENTRIES ARE RANKED BY ASCENDING VALUES OF THE VALUES CONTAINED
49200 C IN THE "IRNK" CELL OF THE "ORDER" ARRAY. IN THE CASE OF A
49300 C TIE, THE FIRST IN FIRST OUT RULE IS APPLIED.
49400 C------------------------
49500 C INPUT VARIABLES.
49600 C------------------------
49700 C JOB- POINTER TO ORDER TO BE RANKED.
49800 C NPTR- POINTER TO HEAD OF THE LIST INTO WHICH THE
49900 C CURRENT ORDER IS TO BE PLACED.
50000 C TIME- IF THE LIST BEING MCT IS THE FUTURE EVENTS LIST,
50100 C THIS VARIABLE IS THE NEXT EVENT TIME. OTHERWISE
50200 C THIS IS A Dummy VARIABLE.
50300 C IRNK- NUMBER OF THE CELL OF "ORDER" WHICH WILL BE USED
50400 C TO RANK THE LIST.
50500 C------------------------
50600 C COMMON /ORDERS/ INDEX(993,6), IORDER(993,1), LORDER(993,20), NAVAIL,
50700 C LAST(IS), NEXT, WPONH, NRHAPP, ORDER(993,9)
50800 C------------------------
50900 C 100 IF(NEXT .GE. 0) GOTO 100
51000 C 150 GOTO 210
51100 C 50 IF(NEXT .GE. 0) GOTO 100
51200 C 500 IF(NEXT .GE. 0) GOTO 100
51300 C------------------------
51400 C CURRENT ENTRY IS ONLY ENTRY IN THE LIST.
51500 C------------------------
51600 C LOCATE CORRECT POSITION OF CURRENT ENTRY IN LIST.
51700 C------------------------
51800 C UPDATE LIST POINTER TO PLACE CURRENT ENTRY INTO LIST.
THIS SUBROUTINE SETS UP THE END-OF-PROCESSING EVENT.

COMMON /TLE1,CLOCK,DTIME,TIME,TDAY,IRUN,ITWEEK,MOE,MONDAY,NSTOP,
INDATE,INDATE,ODAY,AVAL

COMMON /PD1/INW1D((200,7),IVRD((200,15),IMRT((993,2),KROOT((993,2)

,1,MRD((993,2),KROOT((993,2),KROOT((95,25,5)),

24200 COMMON /MEDP71/ KSTAT((11,10),MCHP((12,10),MCHP((5,100),

1MEN(5,100),MEN2,MRP,SMACH(4,100,3),304A((3,10),

20JOB((1,10),31),QSTAT((1,10,3),QSTAT((1,2,9,1),QSTAT((5,2,3,10)

55100 COMMON /PROD2/ OFUL((20,4),IDEK((20,5),IFORE((20,52),IFORF((20,7),IMPG,

180(200),CARRY,(20,5),MEN1,MRP,MR2,ASS1N((4),WIPING,WIFS((6,2)

55300 2ALE(200),UPOR((200)

55500 COMMON /ORDERS/ NEX((993,5),ORDER((993,3),ORDER((993,20),NAVAILABLE,

55600 INDEED(52),MEN2,MRP,MR2,MRHARR,ORDER((973,9)

55700 COMMON /ORDERS/ NEX((993,5),ORDER((993,3),ORDER((993,20),NAVAILABLE,

55800 INDEED(52),MEN2,MRP,MR2,MRHARR,ORDER((973,9)

55900 MEN(2,MAN)=JOB

56000 MEN(3,MAN)=MCH

56100 MACH(1,MCH)=1

56200 MACH(2,MCH)=JOB

56300 MACH(3,MCH)=MAN

56400 PROVCT=HDEN(1,MAN)/100.

56500 ORDER(JOB,10)=MCH

56600 ORDER(JOB,11)=MAN

56700 DETERMINE THE SETUP TIME FOR THE CURRENT OPERATION.

THIS VALUE IS MEASURED IN MINUTES.

57000 STIME=ORDER(JOB,8)

57100 VAIL=STIME/50.

57200 CALL CDATAI(YAIL,QSTAT((1,1,5,MCHP))

57300 CALL CDATAI(YAIL,QSTAT((1,1,5,MCHP))

57400 ORDER(JOB,3)=ORDER(JOB,3)+STIME

57500 SMACH(1,MCH,1)=SMACH(1,MCH,1)+STIME

57600 SMACH(1,MCH,1)=SMACH(1,MCH,1)+STIME

57700 DETERMINE THE RUN TIME FOR THE CURRENT OPERATION. BOTH A

STANDARD AND ACTUAL RUN TIME ARE CALCULATED WITH BOTH VALUES

58000 AIME=STIME+PROVCT

58100 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

58200 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

58300 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

58400 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

58500 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

58600 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

58700 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

58800 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

58900 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

59000 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

59100 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

59200 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

59300 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

59400 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

59500 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

59600 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

59700 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

59800 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

59900 ORDER(JOB,7)=ORDER(JOB,7)+AIME+STIME

60000 DETERMINE THE TIME THEN THE CURRENT OPERATION WILL END

AND PUT THE EVENT INTO THE FUTURE EVENTS LIST.
C ORDER(JOB,1)=CLOCK+ASTIME+ARRIVE
C CALL SORT(JOB,IXY,?RETURN)
C THIS SECTION LOCATES THE INDIVIDUAL COMPONENTS REQUIRED
C BY THE CURRENT OPERATION AND ADJUSTS THEIR ALLOCATED
C INVENTORIES TO REFLECT THE SHIFT TO WORK-IN-PROCESS.
C
IF(NROUT(NJOY,4),,EQ,0) RETURN
IFIRST=4+1-IFIRST
ILAST=4+1-ILAST+1
PART=0.0
RMA T=0.0
DO 100 II=IFIRST,ILAST
JCOM=4+1-II
IQTY=LIST(1)+(1,1)*NROUT(III,1)
INVROF(JCOM,2)=INVROF(JCOM,2)-IQTY
VAL=VAL+INVROF(JCOM,1)+INVROF(JCOM,2)
CALL CSTAT2(VAL,CLOCK,JSTAT2(1,11,JCOM))
VAL=VAL*VALUE(JCOM,1)
CALL CSTAT2(VAL,CLOCK,JSTAT2(1,12,JCOM))
IF(JCOM.LE.JFOG) PART=PART+(IQTY*VALUE(JCOM,1))
IF(JCOM.GT.JFOG) PART=PART+(IQTY*VALUE(JCOM,1))
100 CONTINUE
C UPDATE AGGREGATE INVENTORIES TO REFLECT THE
C SHIFT IN INDIVIDUAL INVENTORIES.
C
ORDER(JOB,3)=ORDER(JOB,3)+PART+?MAT
WIPINV=WIPINV+PART+RMA T
CALL CSTAT2(WIPINV,CLOCK,WIPS(1,1))
AIGNV(1)=AIGNV(1)+PART
CALL CSTAT2(AIGNV(2),CLOCK,ASTAT2(1,1,2))
AIGNV(3)=AIGNV(3)+PART
CALL CSTAT2(AIGNV(3),CLOCK,ASTAT2(1,1,3))
RETURN
END
APPENDIX B

Bill of Material Generator

The following is a listing of the BOM generator for the product structures. The random number generator involved in the Naval Postgraduate School Random Number Generator Package LLRND. (30)
C00100        COMMON /DUTY/ HEX(10), IPARMT(300), JNWP(300), NCRRT(300), NREC(300)
C00200        1), MLEVEL(1), JLEVEL, KLEVEL, LLEVEL, NLDEP, NDEP, IX, CCOP(100), COP
C00300        1(300), CSUT(300), JREF(8), TST(10), PARM(10, 4), RELS, COMMON, RMULT
C00400        COMMON /DOUT/ INWD(300, 4), INWDR(300, 4), OUT(300, 4),
C00500        IOUT(300, 4), JOUT(300, 4, 4, 2), OUT(300, 4, 4), VALUE(300, 2)
C00600        DIMENSION DEPT(4, 10), MCHGRP(10), MRY(100), IDFUN(20, 3), DFUN(20, 4)
C00700        DIMENSION ATRAY(10)
C00800        OPEN(Unit=50, File="?11.DAT")
C00900        C
C01000        C INITIALIZE ALL ARRAYS
C01100        C
C01200        DO 150 I=1, 300
C01300        IPARMT(I)=0
C01400        NREC(I)=0
C01500        NCRRT(I)=0
C01600        NOCDM(I)=0
C01700        COP(I)=0.0
C01800        CSUT(I)=0.0
C01900        DO 140 J=1, 4
C02000        INWDR(I, J)=0
C02100        INWDRH(I, J)=0
C02200        IOUT(I, J)=0
C02300        UQ 130 K=1, 4
C02400        JROUT(I, J, K)=0
C02500        OROUT(I, J, K)=0
C02600        DO 120 L=1, 2
C02700        DROUT(I, J, K, L)=0
C02900        120 CONTINUE
C02900        130 CONTINUE
C03000        140 CONTINUE
C03100        DO 110 N=1, 2
C03200        VALUE(I, N)=0
C03300        110 CONTINUE
C03400        150 CONTINUE
C03500        DO 151 I=1, 10
C03600        CCOP(I)=0.0
C03700        TST(I)=0.0
C03800        NEX(I)=0
C03900        MLEVEL(I)=0
C04000        151 CONTINUE
C04100        C CONTROL PARAMETERS - IDOPT(II)
C04200        C
C04300        I=1 - 1 -- 4 LEVELS IN BOM
C04400        - 2 -- 8 LEVELS IN BOM
C04500        I=2 - 1 -- SMALL NUMBER OF ITEMS/DEPARTMENT
C04600        - 2 -- LARGE NUMBER OF ITEMS/DEPARTMENT
C04700        I=3 - 1 -- SMALL LOT SIZE
C04800        - 2 -- LARGE LOT SIZE
C04900        I=4 - 1 -- SPT RULE
C05000        - 2 -- DUE DATE RULE
C05100        I=5 - 1 -- NO APS VARIABILITY
C05200        - 2 -- HIGH APS VARIABILITY
C05300        I=6 - 1 -- LOWER AVE LOAD
C05400        - 2 -- HIGHER AVE LOAD
C05500        I=7 - 1 -- NO GATEWAY
C05600        - 2 -- GATEWAY IN DEPT. # 1
C05700        I=8 ---- REPLICATION #
C05800        C
C05900        C READ(40, 5000) IDOPT
C06000        C
C5000 FORMAT(J11)
06200 IOPT(1)=1
06300 IOPT(2)=1
06400 IOPT(3)=1
06500 IOPT(4)=1
06600 IOPT(5)=1
06700 IOPT(6)=1
06800 IOPT(7)=1
06900 IOPT(8)=1
07000 C SET UP PARAMETERS FOR ALL DISTRIBUTIONS
07100 C INVENTORY VALUE FOR RAW MATERIALS
07200 C PPARM(1,1)=20.0
07300 C PPARM(1,2)=10.0
07400 C PPARM(1,3)=40.0
07500 C PPARM(1,4)=10.0
07600 C BEGINNING INVENTORY
07700 C PPARM(2,1)=2.0
07800 C PPARM(2,2)=1.0
07900 C PPARM(2,3)=1.0
08000 C PPARM(2,4)=1.0
08100 C WORKER PRODUCTIVITY
08200 C PPARM(3,2)=50.0
08300 C PPARM(3,3)=150.0
08400 C PPARM(3,4)=2.0
08500 C DEMAND SEASONAL VARIATION MAGNITUDE
08600 C PPARM(4,1)=10.0
08700 C PPARM(4,2)=5.0
08800 C PPARM(4,3)=15.0
08900 C PPARM(4,4)=2.0
09000 C SET UP TIME/OPERATION
09100 C PPARM(5,2)=20.0
09200 C PPARM(5,3)=150.0
09300 C PPARM(5,4)=20.0
09400 C OPERATING TIME/OPERATION
09500 C PPARM(6,2)=0.005
09600 C PPARM(6,3)=0.005
09700 C PPARM(6,4)=0.02
09800 C GENERATE BOM STRUCTURE
09900 C IZ=0
10000 C IX=0
10100 C DEMNO=100
10200 C KLEV=0
10300 C KPUR=0
10400 C CMON=0.2
10500 C CARRY=0.25
12100  GAMA=0.85
12200  IF(IOPT(5).EQ.2) GAMMA=0.90
12300  RELS=0.9
12400  KMULT=2.0
12500  XMULT=1.0
12600  IF(IOPT(3).EQ.2) XHULF=2.0
12700  K=1
12800  NEITEM=4
12900  LEVEL=4
13000  IF(IOPT(1).EQ.2) LEVEL=0
13100  NDEPT=8
13200  IF(IOPT(2).EQ.2) NDEPT=4
13300  LITEM=4
13400  LARGE=4
13500  DO 10 KK=L,NEITEM
13600  N=LC(KK)=KK
13700  10 CONTINUE
13800  DO 20 JLF=1,LEVEL
13900  DO 30 I=K,LITEM
14000  CALL PARAM(I)
14100  30 CONTINUE
14200  K=LITEM+1
14300  LITEM=LARGE
14400  20 CONTINUE
14500  C CALCULATE RAW MATERIAL INFORMATION
14700  C
14800  NIG=LARGE
14900  DO 244 II=1,NIG
15000  IF(NCOMX(II).NE.1) GO TO 244
15100  NUM=LARGE+1
15200  IPINT(NUM)=II
15300  LARGE=NUM
15400  NROUT(II,1,1,1)=NUM
15500  NROUT(II,1,1,2)=1
15600  INVROM(NUM,1)=1
15700  INVROM(NUM,2)=1
15800  INVROM(NUM,3)=0
15900  IPAR=1
16000  IVAL=INORM(IPAR)
16100  VALUE(NUM,1)=IVAL
16200  VALUE(NUM,2)=0.0
16300  INVDFD(NUM,1)=10000
16400  INVDFD(NUM,3)=10000
16500  244 CONTINUE
16600  C CALCULATE CUMULATIVE INVENTORY COSTS BASED ON COMPONENTS
16700  C
16800  C
16900  NSIZE=LARGE-NEITEM
17000  DO 101 I=1,NSIZE
17100  LNUM=LARGE+1-I
17200  LNUM=IPARNT(LNUM)
17300  NCOM=NCPRNT(LNUM)
17400  VALUE(LNUM,1)=VALUE(LNUM,1)+VALUE(INUM,1)
17500  IF(NCOM.NE.0) GO TO 101
17600  VALUE(NCOM,1)=VALUE(NCOM,1)+VALUE(INUM,1)
17700  101 CONTINUE
17800  C CALCULATE LOT SIZES
17900  C
18000  C
DO 201 II=1,LARGE
18200 INTEGER=100*100*100
18300 IF(10**8*10**10) INTEGER=100*2
18400 INVRDF(II,2)=SOFT(INTEGER*VALUE(II,2)/VALUE(II,1))
18500 INVRDF(II,2)=INVRDF(II,2)*MULT
18600 201 CONTINUE
18700 C
18800 C COMPUTE INTEGER LOT SIZE FOR COMPONENT
18900 C
19000 INTEGER=INTEGER*1
19100 INTEGER=LARGE*1
19200 DO 211 JJ=1,LARGE,LARGE
19300 INTEGER=PARINTER(JJ)
19400 INTEGER=INTEGER*1
19500 IF(NIGHT=0) GO TO 211
19600 INTEGER=INTEGER*1
19700 IF(INVRDF(II,2)+1) INTEGER=1
19800 INVRDF(JJ,2)=INTEGER+INVRDF(KNUM,2)
19900 CONTINUE
20000 C
20100 C DO 215 KK=LARGE,LARGE
20200 C INVRDF(KK,2)=1000
20300 C INVRDF(KK,4)=RELS*INVRDF(KK,2)
20400 CONTINUE
20500 C
20600 C CALCULATE MIN. RELEASE SIZE, BEGINNING INVENTORY, AND LEAD TIME
20700 C
20800 INTEGER=2
20900 DO 221 KK=1,LARGE
21000 INVRDF(KK,4)=INTEGER*INVRDF(KK,2)+0.5
21100 NIVM=INVRDF(IPAR)
21200 INVRDF(KK,1)=NIVM*INVRDF(KK,2)
21300 PLT=(CSIV(KK)+COPT(KK)*INVRDF(KK,2))/50.0
21400 LT=(PLT+32.0)/40.0+0.5
21500 IF(INVRDF(KK,4)+1) PLT=36.0/40.0
21600 IF(LT+1) LT=1
21700 INVRDF(KK,1)=LT
21800 CONTINUE
21900 C
22000 C WRITE BOM ONTO DISC
22100 C
22200 WRITE(50,601) (IOPT(I),I=1,8)
22300 FORMAT(8I1)
22400 C READ PARMSETERS
22500 C
22600 C
22700 C
22800 C CLEAR=100
22900 C
23000 C
23100 C
23200 C
23300 C
23400 C
23500 C
23600 C
23700 C
23800 C
23900 C
24000 C
```
24100 C  CALCULATE EXPECTED PRODUCTIVITY
24200 C
24300 NN=LARGE-NPUR
24400 DO 65  I=1,NN
24500 XNUM=1.0
24600 IF(NCPANT(I,WE.0) XNUM=1.25
24700 NOP=INVRD(N,1,3)
24800 DO 64 JJ=1,NOP
24900 TST(MROUT(I,JJ,1))=TST(MROUT(I,JJ,1))+(XNUM*GROUT(I,JJ,1)/INVRD(I
25000 1,2))
25100 64 CONTINUE
25200 56 CONTINUE
25300 TAT=STDDAY*NDAYS
25400 DO 71 MIX=1,NDEPT
25500 TIP=(TST(MIX)+CGOPT(MIX))*IDEMb
25600 EX=TIP/(TAT*GMNA)
25700 NEX(MIX)=EX*0.5
25800 IF(NEX(MIX).EQ.0) NEX(MIX)=1
25900 PR=NEX(MIX)/EX
26000 APARK(MIX)=PR*GMNA*100.0
26100 71 CONTINUE
26200 DO 410 IDEPT=1,NDEPT
26300 MDEPT(I,1,IDEPT)=NEX(1,IDEPT)
26400 MDEPT(I,2,IDEPT)=1
26500 MDEPT(I,3,IDEPT)=1
26600 MDEPT(4,IDEPT)=2
26700 IF(IIDPT(4).EQ.2) MDEPT(4,IDEPT)=1
26800 WRITE(50,501)(MDEPT(JJ,IDEPT),JJ=1,4)
26900 PPAK(NJ)=IPARK(IIDPT)
27000 VAL=MDEPT(2,IDEPT)
27100 GO 380 MGRP=1,NVAL
27200 MCHGRP(MGRP)=NEX(IDEPT)
27300 WRITE(50,501) MCHGRP(MGRP)
27400 380 CONTINUE
27500 IVAL=I
27600 IF(NEX(I).GT.5) IVAL=IVAL+1
27700 DO 770 IVAL=1,NVAL
27800 READ(50,501)(AE(I),I=1,NVAL)
27900 770 CONTINUE
28000 55 CONTINUE
28100 WRITE(50,830) (AE(I),I=1,NVAL)
28200 410 CONTINUE
28300 NPRO=LARGE
28400 WRITE(50,825) NPRO,NDIV,NSUM,NPUR,WRITE,NARRY
28500 825 FORMAT(4IS,F10.3)
28600 DO 600 I=1,LARGE
28700 WRITE(50,830) 1,INVRD(I,JJ),JJ=1,4,(INVRD(I,JJ),
28800 JJ=1,3),(VALUE(I,JJ),JJ=1,2)
28900 830 FORMAT(3I3,1X,15I3,1X,15F5.0)
29000 NOP=INVRD(N,1,3)
29100 IF(NOP.EQ.0) GO TO 700
29200 DO 500 JJ=1,NOP
29300 WRITE(50,835) (MROUT(I,JJ,L),L=1,3)
29400 835 FORMAT(16I5)
29500 WRITE(50,840) (MROUT(I,JJ),L=1,2)
29600 840 FORMAT(48I3,1X,15I3,1X,15F5.0)
29700 WRITE(50,835) (MROUT(I,JJ,L),L=1,3)
29800 835 FORMAT(16I5)
29900 WRITE(50,840) (MROUT(I,JJ,L),L=1,2)
30000 840 FORMAT(48I3,1X,15I3,1X,15F5.0)
```
C    END ITEM DEMAND PARAMETERS
C
C  IPAR=4
30800 DO 640 II=1,WEITEM
30900 IFUN(II,1)=II
31000 IFUN(II,2)=II*2+1
31100 IFUN(II,3)=1
31200 DFUN(II,1)=IDEMWD
31300 DFUN(II,2)=0.0
31400 DFUN(II,3)=0.0
31500 IF((IJPFT(5),.EQ.1)) GO TO 611
31600 NUM=1NGAM(IPAR)
31700 DFUN(II,3)=NUM
31800 611 WRITE(50,314) (DFUN(II,JJ),JJ=1,3),(DFUN(II,JJ),II=1,3),
31900 12000 JJ=1,4)
32100 814 FORMAT(315,4F10.2)
32200 640 CONTINUE
32300 STOP
32400 END
32500 SUBROUTINE PARAM(I)
32600 COMMON /BOT1/ NEX(10),IPARNT(300),NPPC3(300),NCPRNT(300),NREC(300)
32700 1),KCLV(10),JLEV,LZ,KLEV,LARGE,LARGE,NCIDT,NPUR,IX,C0PT,COPT
32800 2(300),C0UT(300),J0FT(9),TST(10),PPARW(10,4),RELS,C01N,PMULI
32900 COMMON /PROD/INVROD(300,4),INVROH(300,4),IROUT(300,4),
33000 INVROH(300,4,4),INVROH(300,4,4,2),DISJ(300,4,2),VALDC(300,2)
33100 DIMENSION IJ0PT(300,4)
33200 C    SAFETY STOCK
33300 C
33400 C  INVROD(I,3)=0
33500 C
33600 C  LOT SIZING RULE
33700 C
33800 C  INVROH(I,2)=2
33900 C  IF(JLEV.EQ.1) INVROH(I,2)=1
34000 C
34100 C  IF(PARENT IS COMMON ITEM, USE LAL FOR ITS COMPONENTS.
34200 C
34300 C  IF(NCPRNT(I),.NE.0) INVROH(I,2)=1
34400 C
34500 C  IF(INVROH(IPARNT(I),2).EQ.1.AND.JLEV.GT.2) INVROH(I,2)=1
34600 C
34700 C  GENERATE # OF OPERATIONS/ITEM
34800 C
34900 C  VAL=FAN(C)
35000 C  IF(VAL.LE.0.3333333333333333) NOP=1
35100 C  IF(VAL.GT.0.3333333333333333) NOP=2
35200 C  IF(VAL.GT.0.6666666666666666) NOP=3
35300 C
35400 C  GENERATE ROUTINGS
35500 C
35600 C  DO 550 JJ=1,NOP
35700 550 IJ0FT(I,JJ)=0
35800 60 VAL=FAN(C)
35900 C  IF(IJ0FT(2),.EQ.2) GO TO 900
36000 C  IF(IJ0FT(7),.EQ.1) GO TO 85
36100 C  IF(JJ.EQ.1) GO TO 80
36100 IF (VAL.LE.0.352) MRJUT(I,JJ,1)=1
36200 IF (VAL.LE.0.352.AND.VAL.LT.0.196) MRJUT(I,JJ,1)=2
36300 IF (VAL.LE.0.196.AND.VAL.LT.0.330) MRJUT(I,JJ,1)=3
36400 IF (VAL.LE.0.330.AND.VAL.LT.0.454) MRJUT(I,JJ,1)=4
36500 IF (VAL.LE.0.464.AND.VAL.LT.0.608) MRJUT(I,JJ,1)=5
36600 IF (VAL.LE.0.608.AND.VAL.LT.0.742) MRJUT(I,JJ,1)=6
36700 IF (VAL.LE.0.742.AND.VAL.LT.0.876) MRJUT(I,JJ,1)=7
36800 IF (VAL.LE.0.876) MRJUT(I,JJ,1)=8
36900 GO TO 90
37000 80 IF (VAL.LT.0.230) MRJUT(I,JJ,1)=1
37100 IF (VAL.LE.0.230.AND.VAL.LT.0.340) MRJUT(I,JJ,1)=2
37200 IF (VAL.LE.0.340.AND.VAL.LT.0.450) MRJUT(I,JJ,1)=3
37300 IF (VAL.LE.0.450.AND.VAL.LT.0.560) MRJUT(I,JJ,1)=4
37400 IF (VAL.LE.0.560.AND.VAL.LT.0.670) MRJUT(I,JJ,1)=5
37500 IF (VAL.LE.0.670.AND.VAL.LT.0.780) MRJUT(I,JJ,1)=6
37600 IF (VAL.LE.0.780.AND.VAL.LT.0.900) MRJUT(I,JJ,1)=7
37700 IF (VAL.LE.0.900) MRJUT(I,JJ,1)=8
37800 GO TO 90
37900 85 IF (VAL.LE.0.125) MRJUT(I,JJ,1)=1
38000 IF (VAL.LE.0.125.AND.VAL.LT.0.250) MRJUT(I,JJ,1)=2
38100 IF (VAL.LE.0.250.AND.VAL.LT.0.375) MRJUT(I,JJ,1)=3
38200 IF (VAL.LE.0.375.AND.VAL.LT.0.500) MRJUT(I,JJ,1)=4
38300 IF (VAL.LE.0.500.AND.VAL.LT.0.625) MRJUT(I,JJ,1)=5
38400 IF (VAL.LE.0.625.AND.VAL.LT.0.750) MRJUT(I,JJ,1)=6
38500 IF (VAL.LE.0.750.AND.VAL.LT.0.875) MRJUT(I,JJ,1)=7
38600 IF (VAL.LE.0.875) MRJUT(I,JJ,1)=8
38700 GO TO 90
38800 900 IF (DEPT(7).EQ.1) GO TO 785
38900 IF (JJ.EQ.1) GO TO 780
39000 IF (VAL.LE.0.142) MRJUT(I,JJ,1)=1
39100 IF (VAL.LE.0.142.AND.VAL.LT.0.428) MRJUT(I,JJ,1)=2
39200 IF (VAL.LE.0.428.AND.VAL.LT.0.714) MRJUT(I,JJ,1)=3
39300 IF (VAL.LE.0.714) MRJUT(I,JJ,1)=4
39400 GO TO 90
39500 780 IF (VAL.LT.0.4) MRJUT(I,JJ,1)=1
39600 IF (VAL.LE.0.4.AND.VAL.LT.0.6) MRJUT(I,JJ,1)=2
39700 IF (VAL.LE.0.6.AND.VAL.LT.0.8) MRJUT(I,JJ,1)=3
39800 IF (VAL.LE.0.8) MRJUT(I,JJ,1)=4
39900 GO TO 90
40000 795 IF (VAL.LT.0.25) MRJUT(I,JJ,1)=1
40100 IF (VAL.LE.0.25.AND.VAL.LT.0.50) MRJUT(I,JJ,1)=2
40200 IF (VAL.LE.0.50.AND.VAL.LT.0.75) MRJUT(I,JJ,1)=3
40300 IF (VAL.LE.0.75) MRJUT(I,JJ,1)=4
40400 90 IDEPF(I,JJ)=MRJUT(I,JJ,1)
40500 IF (JJ.EQ.1) GO TO 70
40600 IF (DEPT(I,JJ).EQ.IDEPF(I,JJ-1)) GO TO 50
40700 C # OF ALTERNATIVE MACHINE GROUPS IN DEPARTMENT AND # COMPONENTS
40800 C REQUIRED WITH THE OPERATION
40900 C
41000 C
41100 70 MRJUT(I,JJ,2)=1
41200 IF (JJ.GT.1) GO TO 110
41300 109 VAL=RA(N(0)
41400 41400 IF (VAL.LT.0.1) NCOM=10
41500 IF (VAL.LE.0.1.AND.VAL.LT.0.60) NCOM=1
41600 IF (VAL.LE.0.60) NCOM=2
41700 C
41800 C CHECK TO SEE IF HAVE ENOUGH LEVELS
41900 C
42000 C IF(JLEV.EQ.LEVEL) GO TO 147
42100      NVAL=NREC(I)
42200      IF(MCLEV(NVAL).EQ.JLEV) GO TO 145
42300      IF(NRM.NE.10) GO TO 109
42400      MLEV(NVATL)=MLEV(NVAL)*1
42500      145 IF(MCLEV(NVAL).NE.JLEV) WRITE(5,1001)
42600      1001 FORMAT(1X,"ERROR IN MLEV")
42700 C      DETERMINE IF IS A PURCHASED PART
42800 C
42900 C      NRM=0
43000 C      IF(NCOM.NE.10.AND.JLEV.LT.LEVEL) GO TO 510
43100 C      147 NPUR=NPUR+1
43200 C      NRM=1
43300 C      NCOM=1
43400 C      510 NCOM(I,JJ,3)=NCOM
43500 C      GO TO 150
43600 C
43700 C      110 OUT(I,JJ,3)=0
43800 C
43900 C      ALTERNATE OPERATION, SETUP TIME, AND PROCESSING TIME/OPERATION
44000 C
44100 C      150 IOUT(I,JJ)=1
44200 C      IPAR=5
44300 C      PNVM=10.0
44400 C      IF(IOPT(T).EQ.2) PNVM=5.0
44500 C      X=60.0+(JLEV*NUM)
44600 C      PPARM(IPAR,1)=X
44700 C      VAL=PNRM(IPAR)
44800 C      SUT=VAL
44900 C      CSUT(I)=CSUT(I)+SUT
45000 C      IPAR=5
45100 C      VAL=0.010
45200 C      IF(IOPT(T).EQ.2) AVAL=0.005
45300 C      MLEV=LEVEL+1-JLEV
45400 C      PPARM(I,JJ,1)=MLEV*AVAL
45500 C      RATIO=NNORM(IPAR)
45600 C      OPT=RATIO*SUT
45700 C      IF(OPT.LT.1) OPT=1
45800 C      CPU(T)=CPU(T)+OPT
45900 C      GO 111 NCM=1, NDEP=1
46000 C      IF(NCM(N,JJ,1).GE.IND) GO TO 111
46100 C      XNUM=1.0
46200 C      IF(NCP(N,JJ,1).LE.0) XNUM=1.25
46300 C      CCOPY(IND)=CCOPY(IND)*(XNUM+OPT)
46400 C      111 CONTINUE
46500 C      GOUT(I,JJ,1)=SUT
46600 C      SOUT(I,JJ,2)=OPT
46700 C      IF(JJ.GT.1) GO TO 550
46800 C
46900 C      GENERATE COMPONENT #, QUANTITY OF COMPONENT, AND COMMONALITY
47000 C
47100 C      IF(NRM.NE.1) GO TO 461
47200 C      NCOMPN=1
47300 C      GO TO 550
47400 C      461 GO 530 XF=1,NCOM
47500 C      IF(KK.GT.1) GO TO 400
47600 C      IF(NCOM.EQ.1) GO TO 400
47700 C      IF(JLEV.NLE.2) GO TO 400
47800 C      VAL=RAND(0)
47900 C      IF(JLEV.NLE.COMN) GO TO 400
48000 C      IF(JLEV.NE.KLEV) GO TO 400
48100  NUM=LARGE
48200  NCPUPIC(VU4) = 1
48300  GO TO 410
48400  430  NUM=LARGE+1
48500  IPARN1(NUM) = 1
48600  410  LARGE = VUX
48700  N=DOUT(I,J,K,K,1) = NUM
48800  M=OUT(I,J,J,K,2) = 1
48900  NREC(NUM)=NREC(I)
49000  530  CONTINUE
49100  550  CONTINUE
49200  KLEV = JLEV
49300  C
49400  C  GESPVATE SET UP COSTS - A FUNCTION IF TOTAL SET UP TIME
49500  C
49600  C  VALUE(1,2) = KMULT*CSUT(I)
49700  RETURN
49800  END
49900  C
50000  C  RANDOM NUMBER GENERATORS
50100  C
50200  FUNCTION RNDRA(IPAR)
50300  COMMON /BOTT/ REX(10), IPARN1(300), NJCOMP(300), NCRST(300), NREC(300)
50400  1, J, KLEV(10), JLEV, J, KLEV, LLEV, LLEV, XDEP, XAP, IX, CCOTP(100), C3P1
50500  2(300), N=OUT(300), I=TT(3), I=TT(10), PPARN(10,4), JLEV, XDEP, XAP, RMLT
50600  SUM = 0
50700  DO 101  I = 1, 12
50800  VAL = RAN(0)
50900  101  SUM = SUM + VAL
51000  W = SUM - 5
51100  I = 1, 1, PPARN(IPAR, 4) + PPARN(IPAR, 1)
51200  INORM = INORM + 0.5
51300  IF (INORM - PPARN(IPAR, 2)) 102, 105, 103
51400  102  INORM = PPARN(IPAR, 2)
51500  GO TO 105
51600  103  IF (INORM - PPARN(IPAR, 3)) 105, 105, 104
51700  104  INORM = PPARN(IPAR, 3)
51800  105  RETURN
51900  END
52000  FUNCTION RNDRA(IPAR)
52100  COMMON /BOTT/ REX(10), IPARN1(300), NJCOMP(300), NCRST(300), NREC(300)
52200  1, J, KLEV(10), JLEV, J, KLEV, LLEV, LLEV, XDEP, XAP, IX, CCOTP(100), C3P1
52300  2(300), CSUT(300), J = TOPT(3), I = TT(10), PPARN(10,4), JLEV, XDEP, XAP, RMLT
52400  SUM = 0
52500  DO 101  I = 1, 12
52600  VAL = RAN(0)
52700  101  SUM = SUM + VAL
52800  W = SUM - 5
52900  I = 1, 1, PPARN(IPAR, 4) + PPARN(IPAR, 1)
53000  IF (INORM - PPARN(IPAR, 2)) 102, 105, 103
53100  102  INORM = PPARN(IPAR, 2)
53200  GO TO 105
53300  103  IF (INORM - PPARN(IPAR, 3)) 105, 105, 104
53400  104  INORM = PPARN(IPAR, 3)
53500  105  RETURN
53600  END
APPENDIX C

Product Structures Examples

The following are two example product structures generated by the BOM generator and in the format needed for the MRPSIM simulator. Also included is a schematic for each BOM.
4 Levels in BOM

4

3

2

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APPENDIX D

Research Design of Sample Experiment

\[ 2^{7-4} = 2^3 = 8 \] cells for \( \frac{1}{16} \)th fractional design\(^*\)
saturated design of Resolution III - main effects only.

(1) - all low
I - all high
if letter appears, is at high level.

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<td>B Work center special</td>
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<tr>
<td>C Lot size</td>
<td>1 (xEOQ)</td>
<td>2 (xEOQ)</td>
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<tr>
<td>D Priority rule</td>
<td>DD</td>
<td>SPT</td>
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<tr>
<td>E MPS var.</td>
<td>none</td>
<td>high</td>
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<tr>
<td>F Ave load</td>
<td>( \sim 85 + i )</td>
<td>( \sim 90 + 1 )</td>
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<tr>
<td>G Gateway</td>
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Generators

\[ I = ABD, \ I=ACE, \ I=BCF, \ I=ABCG \]

* see Montgomery (51), pg. 251.
Cells in Fractional Design

ABCG
ABEF
ACDF
AEG
BCDE
BDFG
CEFG
(1)
ALIAS Table  \(2^{7-4}=8\)

\[\begin{align*}
I &= ABD=ACE=BCF=ABCG=BCDE=ACDF=CDG=ABEF=BEG=AFG=DEF=ADEG=CEFG=BD\overline{F}=ABCDEF \\
A &= BD=CE=ABCF=BCG=ABCDE=CDF=ACDG=BEF=ABFG=FG=ADEF=DEG=AC\overline{E}FG=ABDFG=BCDEFG \\
B &= AD=ABCE=CF=ACG=CDE=ABCDF=BCDG=AEG=ABFG=\overline{B}DEF=ABDEG=BCE\overline{F}G=DFG=ACDEFG \\
C &= ABCD=AE=BF=ABG=BD\overline{E}=ADF=DFG=ABCEF=BC\overline{E}G=ACFG=CDEF=ACDEG=EFG=BCDFG=ABDEFG \\
D &= AB=ACDE=BCDF=ABCDG=BCE=ACF=CG=ABDEF=BDEG=ADF\overline{G}=EFG=AC\overline{E}G=CFG=BDFG=ABCEFG \\
E &= ABDE=AC=BCEF=ABC\overline{E}F=BCD=ACDEG=CDEG=ABF=BG=AEFG=DF=ADG=CFG=BDEFG=ABCDFG \\
F &= ABDF=ACEF=BC=ABC\overline{F}G=BCDF=ACD=CD\overline{F}G=ABE=BEFG=AG=DE=ADEF\overline{G}=LEG=BDG=ABCDEG \\
G &= ABDG=ACEG=BGFG=ABC=BCDEG=ACDFG=CD=AB\overline{E}FG=BE=AF=DEFG=ADE=CEF=BF=ABC\overline{E}F
\end{align*}\]
APPENDIX E

Results of Sample Experiment

The following is a listing of the results of the sample experiment. There are 8 observations per replication, and 3 replications. The following is a reference for the headings of each column:

1= Factor at low level
2= Factor at high level
Level = Number of levels in BOM
Items = Degree of work center specialization
Lot = Magnitude of the lot size
Rule= Priority rule
MPS= End item demand variability
Load= Average load level
Gate= Gateway departments

$Y_1$ = Average cumulative end item backorders
$Y_2$ = Average inventory units per average item
$Y_5$ = Average standard deviation of the load across the shop
$Y_3$ = Average standard deviation of the load summed overall departments
$Y_6$ = Autocorrelation of the weekly loads across the shop
$Y_4$ = Autocorrelation of the weekly loads summed over all departments
$Y_7$ = Average total inventory units
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**Observed Values**

**11/28 Monday, December 23, 1993**

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**N=24**
APPENDIX F

Power Analysis of Sample Experiment

The calculations of the power of the test and sample size from the sample experiment's results appear in the following appendix. The calculations are for each of the six performance measures and the seven research factors. The calculations are based upon Cohen's (20) procedures and tables. The power tables are on pp. 281-347, and the sample size tables are on pp. 374-382. The calculations are:

\[ \alpha_A = \sqrt{\frac{SS_A}{df \ model}} \]
\[ \alpha = \sqrt{\text{MSE}} \]
\[ F_A = \frac{\alpha_A}{\alpha} \]

Then with \( df_{\text{numerator}}, df_{\text{denominator}}, \alpha, \) and \( F_A \) for each research factor on each performance measure, using Cohen's tables, the power of the test can be determined. Also, \( n' \), the total sample size for all cells in the experiment can be obtained from the tables. Then the sample size per cell, \( n \), of the main experiment's design can be calculated from the following equation:

303
\[ n = \frac{n'k}{j} \text{ where } k = \text{number of levels/factor} \]
\[ j = \text{number of cells/replication} \]

Also, the power must be specified.

The multiple correlation coefficient, \( R^2 \), shows how much of the variation the independent variables in the regression model can explain. The closer the \( R^2 \) is to 1.0, the better the relationship between the independent variables and the dependent variable.

The following are the parameters used to determine the sample size per cell and power of the experiment.

\[ \text{df numerator} = 1 \]
\[ \text{df denominator} = 16 \]
\[ \alpha = 0.05 \]
\[ \text{Power} = 0.90 \]
\[ k = 2 \]
\[ j = 32 \]
\( \sqrt{\text{MSE}} = 765.3 \)

\( F_{\text{Level}} = \sqrt{\frac{6767308.9/24}{765.3}} = 0.69 \quad \text{Power} = 0.99 \)

\( F_{\text{Item}} = \sqrt{\frac{13710653.8/24}{765.3}} = 0.99 \quad \text{Power} = 0.99 \)

\( F_{\text{Lot}} = \sqrt{\frac{376864.9/24}{765.3}} = 0.16 \quad \text{Power} = 0.08 \)

\( F_{\text{MPS}} = \sqrt{\frac{40544483.1/24}{765.3}} = 1.70 \quad \text{Power} = 0.99 \)

\( F_{\text{Gate}} = \sqrt{\frac{134935.9/24}{765.3}} = 0.10 \quad \text{Power} = 0.03 \)

\( F_{\text{Level}} = \sqrt{\frac{2609282.9/24}{765.3}} = 0.43 \quad \text{Power} = 0.77 \)

\( F_{\text{Item}} = \sqrt{\frac{13054088.3/24}{765.3}} = 0.47 \quad \text{Power} = 0.85 \)

\( F_{\text{Lot}} = \sqrt{\frac{4703162.124}{765.3}} = 0.58 \quad \text{Power} = 0.98 \)

\( R^2 = 0.814 \)
Y2 - Average Inventory Units per Average Item

\[ \sqrt{\text{MS}_E} = 50.03 \]

\[ F_{\text{Level}} = \sqrt{\frac{264293.7/24}{50.03}} = 2.10 \quad \text{Power} = .99 \]

\[ F_{\text{Item}} = \sqrt{\frac{25504.9/24}{50.03}} = .65 \quad \text{Power} = .99 \]

\[ F_{\text{Lot}} = \sqrt{\frac{147471.4/24}{50.03}} = 1.57 \quad \text{Power} = .99 \]

\[ F_{\text{MPS}} = \sqrt{\frac{1008427.7/24}{50.03}} = 4.10 \quad \text{Power} = .99 \]

\[ F_{\text{Gate}} = \sqrt{\frac{1607.2/24}{50.03}} = .16 \quad \text{Power} = .08 \]

\[ F_{\text{Level-Item}} = \sqrt{\frac{11204.2/24}{50.03}} = .43 \quad \text{Power} = .77 \]

\[ F_{\text{Level-MPS}} = \sqrt{\frac{171677.6/24}{50.03}} = 1.69 \quad \text{Power} = .99 \]

\[ F_{\text{Le-It-Mp}} = \sqrt{\frac{13436.9/24}{50.03}} = .47 \quad \text{Power} = .85 \]

\[ F_{\text{Le-Lo-Mp}} = \sqrt{\frac{9875.4124}{50.03}} = .41 \quad \text{Power} = .73 \]

\[ R^2 = .955 \]
Y3 - Average Standard Deviation of the Load Summed over all Departments

\[ \sqrt{\text{MS}_E} = 129.67 \]

\[ F_{\text{Level}} = \sqrt{\frac{556130.9}{24}} = 1.17 \quad \text{Power} = .99 \]

\[ F_{\text{Item}} = \sqrt{\frac{52239.6}{24}} = 1.14 \quad \text{Power} = .99 \]

\[ F_{\text{Lot}} = \sqrt{\frac{45610.5}{24}} = .34 \quad \text{Power} = .53 \]

\[ F_{\text{MPS}} = \sqrt{\frac{954257.9}{24}} = 1.54 \quad \text{Power} = .99 \]

\[ F_{\text{Gate}} = \sqrt{\frac{6151.1}{24}} = .12 \quad \text{Power} = .05 \]

\[ F_{\text{Level-MPS}} = \sqrt{\frac{112634.9}{24}} = .53 \quad \text{Power} = .93 \]

\[ F_{\text{Item-MPS}} = \sqrt{\frac{112878.4}{24}} = .53 \quad \text{Power} = .93 \]

\[ F_{\text{Lot-MPS}} = \sqrt{\frac{112975.8}{24}} = .53 \quad \text{Power} = .93 \]

\[ r^2 = .838 \]
Y4 - Autocorrelation of the Weekly Loads Summed over all Departments

\[ \sqrt{MS_E} = 363.6 \]

\[ F_{Level} = \sqrt{\frac{3214593.5/24}{363.6}} = 1.01 \quad \text{Power} = .99 \]

\[ F_{Item} = \sqrt{\frac{3599296.7/24}{363.6}} = 1.07 \quad \text{Power} = .99 \]

\[ F_{Lot} = \sqrt{\frac{306607.2/24}{363.6}} = .31 \quad \text{Power} = .44 \]

\[ F_{MPS} = \sqrt{\frac{8650576.6/24}{363.6}} = 1.65 \quad \text{Power} = .99 \]

\[ F_{Gate} = \sqrt{\frac{58997.4/24}{363.6}} = .14 \quad \text{Power} = .06 \]

\[ F_{Level-MPS} = \sqrt{\frac{1059255.2/24}{363.6}} = .58 \quad \text{Power} = .97 \]

\[ F_{Item-MPS} = \sqrt{\frac{874026.3/24}{363.6}} = .52 \quad \text{Power} = .93 \]

\[ F_{Lot-MPS} = \sqrt{\frac{956750.5/24}{363.6}} = .55 \quad \text{Power} = .95 \]

\[ R^2 = .835 \]
\[ Y_5 = \text{Average Standard Deviation of the Load across the Shop} \]

\[ \sqrt{MSE} = 116.7 \]

\[ F_{\text{Level}} = \sqrt{\frac{148990.2/24}{116.7}} = 0.68 \quad \text{Power} = 0.99 \]

\[ F_{\text{Item}} = \sqrt{\frac{40293.5/24}{116.7}} = 0.35 \quad \text{Power} = 0.56 \]

\[ F_{\text{Lot}} = \sqrt{\frac{23156.5/24}{116.7}} = 0.27 \quad \text{Power} = 0.32 \]

\[ F_{\text{MPS}} = \sqrt{\frac{344140.6/24}{116.7}} = 1.02 \quad \text{Power} = 0.99 \]

\[ F_{\text{Gate}} = \sqrt{\frac{20426.1/24}{116.7}} = 0.25 \quad \text{Power} = 0.26 \]

\[ F_{\text{Lot-MPS}} = \sqrt{\frac{107187.5/24}{116.7}} = 0.57 \quad \text{Power} = 0.96 \]

\[ R^2 = 0.710 \]
\[ \sqrt{\text{MS}_E} = 315.5 \]

\[
F_{\text{Level}} = \sqrt{\frac{1965958.}{24} \frac{1}{315.5}} = .91 \quad \text{Power} = .99
\]

\[
F_{\text{Item}} = \sqrt{\frac{1646413.}{24} \frac{1}{315.5}} = .83 \quad \text{Power} = .99
\]

\[
F_{\text{Lot}} = \sqrt{\frac{113149.}{24} \frac{1}{315.5}} = .22 \quad \text{Power} = .19
\]

\[
F_{\text{MPS}} = \sqrt{\frac{5386466.6}{24} \frac{1}{315.5}} = 1.50 \quad \text{Power} = .99
\]

\[
F_{\text{Gate}} = \sqrt{\frac{62062.6}{24} \frac{1}{315.5}} = .16 \quad \text{Power} = .08
\]

\[
F_{\text{Lot-MPS}} = \sqrt{\frac{699102.9}{24} \frac{1}{315.5}} = .54 \quad \text{Power} = .94
\]

\[
F_{\text{Level-MPS}} = \sqrt{\frac{690770.8}{24} \frac{1}{315.5}} = .54 \quad \text{Power} = .94
\]

\[
F_{\text{Item-MPS}} = \sqrt{\frac{470083.4}{24} \frac{1}{315.5}} = .44 \quad \text{Power} = .79
\]

\[ R^2 = .804 \]
Y7 - Average Total Inventory Units

\[ \sqrt{MS_E} = 4113.4 \]

\[ F_{Level} = \sqrt{\frac{3342070241.7/24}{4113.4}} = 2.87 \quad \text{Power} = .99 \]

\[ F_{Item} = \sqrt{\frac{391046620.6/24}{4113.4}} = .98 \quad \text{Power} = .99 \]

\[ F_{Lot} = \sqrt{\frac{338815620.3/24}{4113.4}} = .91 \quad \text{Power} = .99 \]

\[ F_{MPS} = \sqrt{\frac{2548285802.1/24}{4113.4}} = 2.51 \quad \text{Power} = .99 \]

\[ F_{Gate} = \sqrt{\frac{30301515.7/24}{4113.4}} = .27 \quad \text{Power} = .29 \]

\[ F_{Level-MPS} = \sqrt{\frac{91410211.3/24}{4113.4}} = .47 \quad \text{Power} = .85 \]

\[ F_{Item-MPS} = \sqrt{\frac{247415164.7/24}{4113.4}} = .78 \quad \text{Power} = .99 \]

\[ F_{MPS-Gate} = \sqrt{\frac{127502347.7/24}{4113.4}} = .56 \quad \text{Power} = .95 \]

\[ F_{Level-MPS-Gate} = \sqrt{\frac{86500393.1/24}{4113.4}} = .46 \quad \text{Power} = .83 \]

\[ R^2 = .933 \]
APPENDIX G

Results of the Main Experiment

The following is a listing of the results of the main experiment. There are 32 cells per replication and 2 replications. The same headings as in Appendix E are used for the five research factors and 7 performance measures.
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APPENDIX H

Power Analysis of Main Experiment

The calculations of the power of the test for the main experiment's results appear in the following appendix. The calculations are for each of the seven performance measures and the five research factors, and significant interactions. The calculations were performed the same as in Appendix F.

\[ \text{df}_{\text{numerator}} = 1 \]
\[ \text{df}_{\text{denominator}} = 32 \]
\[ \alpha = .01 \]
\[
Y_1 = \text{Average Cumulative End Item Backorders}
\]

\[
\sqrt{\text{MS}_E} = 1106.3
\]

\[
\begin{align*}
F_{\text{Level}} &= \sqrt{\frac{739034/24}{1106.3}} = .16 \\
&\quad n' = 214 \quad n = 13 \\
&\quad \text{Power} = .13 \\
F_{\text{Item}} &= \sqrt{\frac{1130787.5/24}{1106.3}} = .62 \\
&\quad n' = 15 \quad n = 1 \\
&\quad \text{Power} = .92 \\
F_{\text{Lot}} &= \sqrt{\frac{396409.7/24}{1106.3}} = .12 \\
&\quad n' = 400 \quad n = 25 \\
&\quad \text{Power} = .10 \\
F_{\text{Rule}} &= \sqrt{\frac{333400/24}{1106.3}} = .11 \\
&\quad n' = 460 \quad n = 29 \\
&\quad \text{Power} = .09 \\
F_{\text{MPS}} &= \sqrt{\frac{27537531.2/24}{1106.3}} = .97 \\
&\quad n' = 9 \quad n = 1 \\
&\quad \text{Power} = .99 \\
F_{\text{Load}} &= \sqrt{\frac{93396.6/24}{1106.3}} = .06 \\
&\quad n' = 1800 \quad n = 112 \\
&\quad \text{Power} = .06 \\
F_{\text{Gate}} &= \sqrt{\frac{8118473/24}{1106.3}} = .53 \\
&\quad n' = 20 \quad n = 1 \\
&\quad \text{Power} = .85
\end{align*}
\]

\[R^2 = .713\]
\[ Y_2 = \text{Average Inventory Units per Average Item} \]

\[ \sqrt{\frac{\text{MS}_E}{44.12}} = 44.12 \]

\[ F_{\text{Level}} = \sqrt{\frac{52950.2/24}{44.12}} = 1.06 \quad n' = 9 \quad n = 1 \quad \text{Power} = .99 \]

\[ F_{\text{Item}} = \sqrt{\frac{22757.5/24}{44.12}} = .70 \quad n' = 12 \quad n = 1 \quad \text{Power} = .97 \]

\[ F_{\text{Lot}} = \sqrt{\frac{178927.6/24}{44.12}} = 1.96 \quad n' = 9 \quad n = 1 \quad \text{Power} = .99 \]

\[ F_{\text{Rule}} = \sqrt{\frac{1385./24}{44.12}} = .17 \quad n' = 194 \quad n = 12 \quad \text{Power} = .15 \]

\[ F_{\text{MPS}} = \sqrt{\frac{320392.4/24}{44.12}} = 2.62 \quad n' = 9 \quad n = 1 \quad \text{Power} = .99 \]

\[ F_{\text{Load}} = \sqrt{\frac{4552.9/24}{44.12}} = .31 \quad n = 56 \quad n = 4 \quad \text{Power} = .40 \]

\[ F_{\text{Gate}} = \sqrt{\frac{20739.9/24}{44.12}} = .67 \quad n' = 13 \quad n = 1 \quad \text{Power} = .95 \]

\[ R^2 = .951 \]
Y3 - Average Standard Deviation of the Load Summed over all Departments

\[ \sqrt{\text{MSE}} = 168.3 \]

\[
F_{\text{Level}} = \sqrt{\frac{391985.6/24}{168.3}} = .76 \quad n' = 10 \quad n = 1
\]

Power = .98

\[
F_{\text{Item}} = \sqrt{\frac{214952/24}{168.3}} = .56 \quad n' = 18 \quad n = 1
\]

Power = .85

\[
F_{\text{Lot}} = \sqrt{\frac{178.7/24}{168.3}} = .02 \quad n' = 3000 \quad n = 188
\]

Power = .03

\[
F_{\text{Rule}} = \sqrt{\frac{21141.1/24}{168.3}} = .18 \quad n' = 172 \quad n = 11
\]

Power = .16

\[
F_{\text{MPS}} = \sqrt{\frac{323782.1/24}{168.3}} = .69 \quad n' = 13 \quad n = 1
\]

Power = .96

\[
F_{\text{Load}} = \sqrt{\frac{21986.3/24}{168.3}} = .18 \quad n' = 172 \quad n = 11
\]

Power = .17

\[
F_{\text{Gate}} = \sqrt{\frac{129720.2/24}{168.3}} = .44 \quad n' = 39 \quad n = 2
\]

Power = .68

\[ R^2 = .709 \]
Y4 - Autocorrelation of the Weekly Loads Summed over all Departments

\[
\sqrt{\text{MS}_E} = 470.3
\]

\[
\begin{align*}
F_{\text{Level}} &= \sqrt{\frac{2563255.8/24}{470.3}} = .69 & n' = 13 & n = 1 \\
F_{\text{Item}} &= \sqrt{\frac{1530841.9/24}{470.3}} = .54 & n' = 20 & n = 1 \\
F_{\text{Lot}} &= \sqrt{\frac{7129.4/24}{470.3}} = .04 & n' = 2300 & n = 144 \\
F_{\text{Rule}} &= \sqrt{\frac{215224.7/24}{470.3}} = .20 & n' = 132 & n = 8 \\
F_{\text{MPS}} &= \sqrt{\frac{3115290.7/24}{470.3}} = .77 & n' = 10 & n = 1 \\
F_{\text{Load}} &= \sqrt{\frac{181129.2/24}{470.3}} = .18 & n' = 172 & n = 11 \\
F_{\text{Gate}} &= \sqrt{\frac{921478.4/24}{470.3}} = .42 & n' = 31 & n = 2 \\
\end{align*}
\]

Power = \begin{align*}
.96 \\
.84 \\
.05 \\
.19 \\
.98 \\
.17 \\
.64
\end{align*}

\[R^2 = .707\]
Y5 - Average Standard Deviation of the Load across the Shop

\[ \sqrt{\text{MSE}} = 90.5 \]

\[
F_{\text{Level}} = \sqrt{\frac{102914.9/24}{90.5}} = .72 \quad n' = 11 \quad n = 1 \\
\text{Power} = .98
\]

\[
F_{\text{Item}} = \sqrt{\frac{4102.2/24}{90.5}} = .14 \quad n' = 294 \quad n = 18 \\
\text{Power} = .11
\]

\[
F_{\text{Lot}} = \sqrt{\frac{6144.3/24}{90.5}} = .18 \quad n' = 172 \quad n = 11 \\
\text{Power} = .17
\]

\[
F_{\text{Rule}} = \sqrt{\frac{1207.4/24}{90.5}} = .08 \quad n' = 1126 \quad n = 70 \\
\text{Power} = .08
\]

\[
F_{\text{MPS}} = \sqrt{\frac{97373.1/24}{90.5}} = .70 \quad n' = 12 \quad n = 1 \\
\text{Power} = .97
\]

\[
F_{\text{Load}} = \sqrt{\frac{2178.7/24}{90.5}} = .11 \quad n' = 466 \quad n = 29 \\
\text{Power} = .09
\]

\[
F_{\text{Gate}} = \sqrt{\frac{10086.4/24}{90.5}} = .23 \quad n' = 107 \quad n = 7 \\
\text{Power} = .24
\]

\[ R^2 = .631 \]
Y6 - Autocorrelation of the Weekly Loads across the Shop

\[ \sqrt{\frac{\text{MS}_E}{\text{MS}_E}} = 335.1 \]

\[
F_{\text{Level}} = \sqrt{\frac{1460266.7/24}{335.1}} = 0.74 \\
\text{n'} = 28 \quad n = 2 \\
\text{Power} = 0.98
\]

\[
F_{\text{Item}} = \sqrt{\frac{572268.2/24}{335.1}} = 0.46 \\
\text{n'} = 2500 \quad n = 157 \\
\text{Power} = 0.71
\]

\[
F_{\text{Lot}} = \sqrt{\frac{2128.2/24}{335.1}} = 0.03 \\
\text{n'} = 194 \quad n = 12 \\
\text{Power} = 0.15
\]

\[
F_{\text{Rule}} = \sqrt{\frac{73926.0/24}{335.1}} = 0.17 \\
\text{n'} = 9 \quad n = 1 \\
\text{Power} = 0.99
\]

\[
F_{\text{MPS}} = \sqrt{\frac{1777792.7/24}{335.1}} = 0.81 \\
\text{n'} = 172 \quad n = 11 \\
\text{Power} = 0.17
\]

\[
F_{\text{Gate}} = \sqrt{\frac{403522.7/24}{335.1}} = 0.39 \\
\text{n'} = 36 \quad n = 2 \\
\text{Power} = 0.58
\]

\[ R^2 = 0.709 \]
\[ \sqrt{\text{MS}_E} = 6382.2 \]

\[
\begin{align*}
F_{\text{Level}} &= \frac{1485363077.8/24}{6382.2} = 1.23 \quad n' = 9 \quad n = 1 \\
& \quad \text{Power} = .99 \\
F_{\text{Item}} &= \frac{10033770.7/24}{6382.2} = .10 \quad n' = 526 \quad n = 33 \\
& \quad \text{Power} = .08 \\
F_{\text{Lot}} &= \frac{47651506.5/24}{6382.2} = .22 \quad n' = 114 \quad n = 7 \\
& \quad \text{Power} = .21 \\
F_{\text{Rule}} &= \frac{201199.4/24}{6382.2} = .01 \quad n' = 3000 \quad n = 188 \\
& \quad \text{Power} = .01 \\
F_{\text{MPS}} &= \frac{315266766.8/24}{6382.2} = .57 \quad n' = 18 \quad n = 1 \\
& \quad \text{Power} = .87 \\
F_{\text{Load}} &= \frac{19343909.0/24}{6382.2} = .14 \quad n' = 300 \quad n = 19 \\
& \quad \text{Power} = .11 \\
F_{\text{Gate}} &= \frac{10414046.0/24}{6382.2} = .33 \quad n' = 50 \quad n = 3 \\
& \quad \text{Power} = .40 \\
\end{align*}
\]

\[ R^2 = .753 \]
APPENDIX I

Example FOQ and
Discriminant Rankings Calculations

The following shows the calculations using EOQ logic and integer multiples for component parts. Common parts have the largest integer multiples between the parents. The technique uses the equation \( Q = \sqrt{\frac{2DS}{I}} \) for each component, and then uses the rounded integer multiple of its parent as its lot size.

Yearly demand = 5200 for A and B
<table>
<thead>
<tr>
<th>I</th>
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<th>EOQ</th>
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<tr>
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<tr>
<td>B</td>
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</tr>
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<td>C</td>
<td>55</td>
<td>170</td>
</tr>
<tr>
<td>D</td>
<td>40</td>
<td>190</td>
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<tr>
<td>E</td>
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<td>F</td>
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<td>G</td>
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<td>H</td>
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<td>I</td>
<td>40</td>
<td>220</td>
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<td>K</td>
<td>50</td>
<td>225</td>
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### Discriminant Rankings Calculations

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<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1 (4329.05)</td>
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</tr>
<tr>
<td>Y2 (283.02)</td>
<td>(-.00342973)</td>
<td>-.971</td>
</tr>
<tr>
<td>Y3 (733.52)</td>
<td>(-.01036874)</td>
<td>-7.606</td>
</tr>
<tr>
<td>Y4 (2056.61)</td>
<td>(.00441992)</td>
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</tr>
<tr>
<td>Y5 (660.00)</td>
<td>(-.00557706)</td>
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</tr>
<tr>
<td>Y6 (1784.50)</td>
<td>(.00143860)</td>
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</tr>
<tr>
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**Items**

<table>
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**Lot**

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**End Item**

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<tr>
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<tr>
<td>Y7 (23269.18)</td>
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APPENDIX J

ANOVA Results

The following tables represent the results of the SAS GLM ANOVA analysis for the 5 main effects and interactions in relation to each of the seven performance criteria. The research factors and their interactions, and performance measures are abbreviated according to the notation described in Appendix E.
## FULL FACTORIAL-1,2,3,4 XWAY INTER.-GLM- ZAPPLICATIONS
### GENERAL LINEAR MODELS PROCEDURE

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE Y1</th>
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<th>SUM OF SQUARES</th>
<th>MEAN SQUARE</th>
<th>F VALUE</th>
<th>P &gt; F</th>
<th>R-SQUARE</th>
<th>C.V.</th>
</tr>
</thead>
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<td>0.8115</td>
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<tr>
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<td>0.0001</td>
<td>0.9115</td>
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<td>1093/199329/00</td>
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### SOURCE

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<th>TYPE 3 SS</th>
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### General Linear Models Procedure

**Dependent Variable:** Y2

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328
### General Linear Models Procedure

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

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### General Linear Models Procedure

**Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **PR > F** | **R-Square** | **C.V.**
--- | --- | --- | --- | --- | --- | --- | ---
**Model** | 31 | 2142729.39 | 69.13 | 5.23 | 0.0001 | 0.8371 | 30.467
**Error** | 32 | 5252632.66 | 164.15 | 132176.02 | 191406 | 0.0000 | 7.427
**Corrected Total** | 63 | 7395462.05 | 119.26 | 23.50 | 0.0000 | 0.317

| Source | **DF** | **Type I SS** | **F Value** | **PR > F** | **DF** | **Type IV SS** | **F Value** | **PR > F** |
--- | --- | --- | --- | --- | --- | --- | --- | ---
**Levels** | | | | | | | | |
**Type** | 3 | 184507.00 | 20.73 | 0.0001 | 1214507.00 | 23.81 | 0.0001 |
**Lift** | 1 | 366753.41 | 42.14 | 0.0001 | | | | |
**Rate** | 1 | 465037.72 | 54.05 | 0.0001 | | | | |
**Date** | 8 | 586453.19 | 68.06 | 0.0001 | | | | |
**Season** | 2 | 123748.10 | 14.24 | 0.0001 | | | | |
**Level** | 2 | 122905.10 | 14.03 | 0.0001 | | | | |
**Price** | 1 | 822720.16 | 97.06 | 0.0001 | | | | |
**Term** | 1 | 11759.41 | 1.36 | 0.2496 | | | | |
**Type** | 2 | 119750.52 | 13.94 | 0.0001 | | | | |
**Lift** | 1 | 208593.40 | 24.37 | 0.0001 | | | | |
**Rate** | 1 | 166003.40 | 19.64 | 0.0001 | | | | |
**Date** | 8 | 121780.30 | 14.18 | 0.0001 | | | | |
**Season** | 2 | 122905.10 | 14.03 | 0.0001 | | | | |
**Level** | 2 | 122905.10 | 14.03 | 0.0001 | | | | |
**Price** | 1 | 822720.16 | 97.06 | 0.0001 | | | | |
**Term** | 1 | 11759.41 | 1.36 | 0.2496 | | | | |
**Type** | 2 | 119750.52 | 13.94 | 0.0001 | | | | |
**Lift** | 1 | 208593.40 | 24.37 | 0.0001 | | | | |
**Rate** | 1 | 166003.40 | 19.64 | 0.0001 | | | | |
**Date** | 8 | 121780.30 | 14.18 | 0.0001 | | | | |
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**Term** | 1 | 11759.41 | 1.36 | 0.2496 | | | | |
**Type** | 2 | 119750.52 | 13.94 | 0.0001 | | | | |
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**Rate** | 1 | 166003.40 | 19.64 | 0.0001 | | | | |
**Date** | 8 | 121780.30 | 14.18 | 0.0001 | | | | |
**Season** | 2 | 122905.10 | 14.03 | 0.0001 | | | | |
**Level** | 2 | 122905.10 | 14.03 | 0.0001 | | | | |
**Price** | 1 | 822720.16 | 97.06 | 0.0001 | | | | |
**Term** | 1 | 11759.41 | 1.36 | 0.2496 | | | | |
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332
### FULL FACTORIAL-1,2,3,4-SY-WAY INTER.-GLM- 20 REPETITIONS

#### GENERAL LINEAR MODELS PROCEDURE

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**Note:** This table represents the results of a full factorial experiment with 1, 2, 3, 4-way interactions, analyzed using the GLM method with 20 replications. The F-values and their associated probabilities (PR > F) are provided for each source of variation, along with the sum of squares and mean squares for each term. The A-square and C.V. values also indicate the effect size and variability for each source.
APPENDIX K

Means for Levels of Research Factors

The following tables represent the means for each level of each of the research factors and interactions. The same abbreviations are utilized in Appendix E are used here.
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### Full Factorial - 2, 3, 4, 5, 6 Way Inter. GLM - Replications

**General Linear Models Procedure**

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340
### FULL FACTORIAL-1,2,3,4,5-WAY INTER-666-2REPlications

**11:52 Monday, December 26, 19...**

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**GENERAL LINEAR MODELS PROCEDURE**
APPENDIX L

MANOVA Results

The following table represents the results of the SAS GLM MANOVA analysis for the 31 main effects and interactions in relation to the vector of the seven performance criteria. The research factors and their interactions are abbreviated according to the following notation when the factors are at their high level:

- L - # of levels in the BOM
- I - degree of work center specialization
- M - magnitude of the lot size
- E - end item demand variability
- G - gateway department

The results are presented in terms of approximate F-ratios and their corresponding statistical significance.
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APPENDIX M

Values of Parameters in Study

The following table represents the research settings for all of the research factors, simulation parameters, and various other factors that impact upon the results of this study. Consequently, this table attempts to define the research setting of this study.
### Product Information
- # of levels in BOM: 4 or 8
- # of items/BOM: 25 - 200
- # of end items: 4
- # of parents/component: 80% have 1, 20% have 2
- # of components/parent: uniform-0,1,2
- quantity of component: 1/parent
- # of operations/item: uniform-1,2,3
- lot size (FOQ): range-1-20 wks of demand
- planned lead time: range-1-9 wks
- actual lead time: range-1-20 wks
- cost of setup/item: range-$65-755
- setup time/item: range-20-150 min.
- proc. time/item: range-1-9 min.
- actual proc./setup time ratio: average-9/1 ratio
- minimum release size:
- safety stock: none
- # of nonpurchased items:
  - 4 level-range-18-38
  - 8 level-range-56-137

### Shop Information
- inventory record keeping: perfect accuracy
- labor substitutability: flex. within a dept.
- type of shop: random routed
- priority rule: D.D. or SPT (FIFO tie breaker)
- average load on shop: 85% or 90% ± .5%
- alternate routing: none
- # of machines/dept.: range-1-7
- # of items/dept.: range-4-40
- average load/dept.: 85% ot 90% ± .5%

### Demand Information
- forecast error: none
- average demand: 100 units/wk./end item
- replacement parts orders: none
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<th>Feature</th>
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<td>lot size rule of purch.mat.</td>
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<td>seasonal pattern</td>
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BIBLIOGRAPHY


351


