2000

A model for production scheduling and sequencing using constraints management and genetic algorithm

Ahmad Nadeem Choudhry

University of Northern Iowa

Copyright ©2000 Ahmad Nadeem Choudhry

Follow this and additional works at: https://scholarworks.uni.edu/etd

Part of the Operations Research, Systems Engineering and Industrial Engineering Commons

Let us know how access to this document benefits you

Recommended Citation

https://scholarworks.uni.edu/etd/743

This Open Access Dissertation is brought to you for free and open access by the Student Work at UNI ScholarWorks. It has been accepted for inclusion in Dissertations and Theses @ UNI by an authorized administrator of UNI ScholarWorks. For more information, please contact scholarworks@uni.edu.
INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

Bell & Howell Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI®
A MODEL FOR PRODUCTION SCHEDULING AND SEQUENCING USING
CONSTRAINTS MANAGEMENT AND GENETIC ALGORITHM

A Dissertation

Submitted

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Industrial Technology

Approved:

Dr. Mohammed F. Fahmy, Faculty Advisor

Dr. MD Salim, Co-Advisor

Dr. Douglas Pine, Committee Member

Dr. Michael Spencer, Committee Member

Dr. Barry Wilson, Committee Member

Ahmad Nadeem Choudhry

University of Northern Iowa

December 2000
A MODEL FOR PRODUCTION SCHEDULING AND SEQUENCING USING
CONSTRAINTS MANAGEMENT AND GENETIC ALGORITHM

An Abstract of a Dissertation

Submitted

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Industrial Technology

Approved:

[Signature]

Dr. Mohammed F. Fahmy, Faculty Advisor

[Signature]

Dr. John W. Somervill, Dean of the Graduate College

Ahmad Nadeem Choudhry

University of Northern Iowa

December 2000

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
ABSTRACT

Production planning and control (PP&C) are among the most critical activities in manufacturing. Proper use of PP&C methods can give organizations a competitive advantage in the global economy. The expected results of this research will allow manufacturing organizations to maximize the effectiveness of PP&C methods, thereby improving their competitive position in the global economy.

This research was an extension of a previous unpublished study, which investigated the PP&C methods being used at a midwestern manufacturer of agricultural equipment (MMAE). The current research study identified the constraints inherent in the production planning and control system and then developed and validated a master production scheduling and sequencing optimization model based on constraints management and utilizing genetic algorithms.

The specific objectives of this research were as follows: (a) identify the system’s constraint, (b) develop a scheduling and sequencing model to address the identified constraints, (c) develop and validate the proposed model by simulation, and (d) identify and document improvements attributed to the operational change resulting from the implementation of the optimization model.

The research examined the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on five variables for the final assembly line and four downstream processes at an engine manufacturing plant of a MMAE. The variables were cycle time, queue size, utilization of work centers, flow rate of engines, and total output of engines.
A two-part model, based on constraints management philosophy of production planning and control methods, was developed by the researcher in Excel, one part for scheduling and the other for sequencing. Using data from 100 production days during the fall of 1999 and the spring of 2000, simulations for the current scheduling and sequencing method (the control condition) and for the proposed method (the experimental condition) were compared. Output from the simulations for the experimental and control conditions was statistically analyzed.

The results of this research indicated (a) cycle time for the experimental condition was reduced, but the reduction was not statistically significant; (b) queue size for the experimental condition was also reduced, as expected, but once again, the reduction was not statistically significant; (c) total utilization of work centers was increased, as expected, and the increase was statistically significant; (d) the experimental condition’s simulation results indicated very minimal improvements for the even flow of engines; and (e) the average total number of engines processed for the experimental condition was increased, as expected, and the increase was statistically significant.
DEDICATION

This doctoral dissertation is dedicated
To my mother, who dedicated
her life for the sake of mine.
To my mother, I am eternally grateful
ACKNOWLEDGMENTS

The writer praises Almighty Allah for His blessing, support, and guidance that was necessary for the completion of this research project. The author would also like to acknowledge all the people who lent their support, guidance, love, and assistance toward the successful completion of this study. Most notably, the author would like to thank his doctoral committee members for their unconditional support and guidance.

The author would like to thank Dr. Mohammed F. Fahmy, department head and committee advisor, for his unconditional support and guidance throughout the DIT program. The author would also like to thank Dr. MD Salim, co-advisor, for his valuable suggestions. The author would also like to express his appreciation to Dr. Douglas Pine, committee member, for his imperative suggestions from the very early stages of this project. Likewise, special thanks are extended to Dr. Michael S. Spencer, committee member, for providing guidance in the early stages of this project and for valuable comments and suggestions; Dr. Barry Wilson, committee member, for providing his statistical expertise; and Cheryl Smith for her valuable editing and suggestions.

This research project could not have been completed without support from Deere & Company. I would like to extend my sincere thanks to all the Deere & Company employees for their technical help, valuable suggestions, and assistance in relating academic aspects of production planning and control systems in a practical way. The author would like to especially thank Mr. Gordon Rehn for providing simulation expertise for this study.

Finally, the author would like to express very special gratitude to my wife, Arfana, and my children, Aisha, Omer, Bilal, and Fatima, for their understanding and
support. To my wife, I owe a great debt for her patience throughout this project. Without her unconditional support, this research would not have been possible.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>LIST OF TABLES</th>
<th>ix</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF FIGURES</td>
<td>x</td>
</tr>
<tr>
<td>CHAPTER I: INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Background</td>
<td>1</td>
</tr>
<tr>
<td>Manufacturing after World War II</td>
<td>1</td>
</tr>
<tr>
<td>Evolution of the Production Planning and Control Systems</td>
<td>2</td>
</tr>
<tr>
<td>Statement of the Problem</td>
<td>6</td>
</tr>
<tr>
<td>Statement of the Purpose</td>
<td>6</td>
</tr>
<tr>
<td>Importance of the Research</td>
<td>7</td>
</tr>
<tr>
<td>Research Questions</td>
<td>9</td>
</tr>
<tr>
<td>Assumptions</td>
<td>11</td>
</tr>
<tr>
<td>Limitations</td>
<td>11</td>
</tr>
<tr>
<td>Definition of Terms</td>
<td>11</td>
</tr>
<tr>
<td>CHAPTER II: REVIEW OF LITERATURE</td>
<td>14</td>
</tr>
<tr>
<td>Material Requirements Planning</td>
<td>15</td>
</tr>
<tr>
<td>Evolution</td>
<td>15</td>
</tr>
<tr>
<td>Functionality</td>
<td>19</td>
</tr>
<tr>
<td>Advantages and Disadvantages</td>
<td>21</td>
</tr>
<tr>
<td>Just-in-Time</td>
<td>23</td>
</tr>
<tr>
<td>Evolution</td>
<td>23</td>
</tr>
<tr>
<td>Functionality</td>
<td>24</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequencing model</td>
<td>78</td>
</tr>
<tr>
<td>Site Selection</td>
<td>85</td>
</tr>
<tr>
<td>Software Selection</td>
<td>86</td>
</tr>
<tr>
<td>Data Collection</td>
<td>87</td>
</tr>
<tr>
<td>Statistical Analysis</td>
<td>88</td>
</tr>
<tr>
<td>Model Validation</td>
<td>90</td>
</tr>
<tr>
<td>Summary</td>
<td>92</td>
</tr>
<tr>
<td>CHAPTER IV: SIMULATION RESULTS AND DISCUSSION</td>
<td>94</td>
</tr>
<tr>
<td>Cycle Time</td>
<td>101</td>
</tr>
<tr>
<td>Queue Size</td>
<td>103</td>
</tr>
<tr>
<td>Utilization of Work Centers</td>
<td>106</td>
</tr>
<tr>
<td>Flow Rate of Engines</td>
<td>111</td>
</tr>
<tr>
<td>Total Output of Engines</td>
<td>114</td>
</tr>
<tr>
<td>CHAPTER V: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS</td>
<td>120</td>
</tr>
<tr>
<td>Summary</td>
<td>120</td>
</tr>
<tr>
<td>Conclusions</td>
<td>121</td>
</tr>
<tr>
<td>Recommendations</td>
<td>123</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>125</td>
</tr>
<tr>
<td>APPENDEX A</td>
<td>133</td>
</tr>
<tr>
<td>Simulation Output (Control Condition)</td>
<td>133</td>
</tr>
<tr>
<td>Simulation Output (Experimental Condition)</td>
<td>140</td>
</tr>
</tbody>
</table>
APPENDEX B ................................................................................................................147
  Simulation Code ........................................................................................................... 147
APPENDEX C ..................................................................................................................201
  Snapshot of Animated Simulation Run ......................................................................... 201
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Time-phased MRP requirements processing</td>
<td>20</td>
</tr>
<tr>
<td>2. Fitness test</td>
<td>33</td>
</tr>
<tr>
<td>3. Line-up dates and test numbers</td>
<td>95</td>
</tr>
<tr>
<td>4. Comparison data for cycle time</td>
<td>103</td>
</tr>
<tr>
<td>5. Comparison data for queue size</td>
<td>105</td>
</tr>
<tr>
<td>6. Utilization of work centers for the control condition</td>
<td>108</td>
</tr>
<tr>
<td>7. Utilization of work centers for the experimental condition</td>
<td>108</td>
</tr>
<tr>
<td>8. Comparison data for utilization of work centers</td>
<td>109</td>
</tr>
<tr>
<td>9. Comparison data for paint utilization</td>
<td>111</td>
</tr>
<tr>
<td>10. Flow rate of engines for the control condition (minutes/engines)</td>
<td>112</td>
</tr>
<tr>
<td>11. Flow rate of engines for the experimental condition (minutes/engines)</td>
<td>112</td>
</tr>
<tr>
<td>12. Comparison data for even flow</td>
<td>113</td>
</tr>
<tr>
<td>13. Comparison data for total output</td>
<td>116</td>
</tr>
<tr>
<td>14. Number of engines processes in the system (control condition)</td>
<td>117</td>
</tr>
<tr>
<td>15. Number of engines processes in the system (experimental condition)</td>
<td>117</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Production planning and control hierarchy for pull system</td>
<td>3</td>
</tr>
<tr>
<td>2. Closed loop MRP</td>
<td>17</td>
</tr>
<tr>
<td>3. Manufacturing resource planning</td>
<td>18</td>
</tr>
<tr>
<td>4. A typical bill of material</td>
<td>19</td>
</tr>
<tr>
<td>5. Crossover operation</td>
<td>34</td>
</tr>
<tr>
<td>6. Control group flow chart for the master scheduling and line-up process</td>
<td>51-52</td>
</tr>
<tr>
<td>7. Experimental group flow chart for the master scheduling and line-up process</td>
<td>53-54</td>
</tr>
<tr>
<td>8. The application of CM at EMP</td>
<td>56</td>
</tr>
<tr>
<td>9. Flow of engines at EMP</td>
<td>57</td>
</tr>
<tr>
<td>10. Flow rate of engines at EMP</td>
<td>58</td>
</tr>
<tr>
<td>11. Import new orders</td>
<td>60</td>
</tr>
<tr>
<td>12. Format orders</td>
<td>62</td>
</tr>
<tr>
<td>13. Format orders with formulas visible in the cells</td>
<td>63</td>
</tr>
<tr>
<td>14. Sort orders</td>
<td>64</td>
</tr>
<tr>
<td>15. Sort orders with formulas visible in the cells</td>
<td>65</td>
</tr>
<tr>
<td>16. Comparison</td>
<td>67</td>
</tr>
<tr>
<td>17. Comparison with formulas visible in the cells</td>
<td>68</td>
</tr>
<tr>
<td>18. Optimization tab, available capacity section</td>
<td>69</td>
</tr>
<tr>
<td>19. Optimization tab, available capacity section, with formulas</td>
<td>70</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
37. Total engines processed in the system ................................................................. 115
38. Paint output for the control and experimental conditions ............................... 118
CHAPTER I
INTRODUCTION

Background

Manufacturing after World War II

World War II brought about many changes to the manufacturing industry worldwide. Manufacturing in America flourished during the war because its industrial infrastructure base had remained intact whereas the industrial infrastructures in Europe, Russia, and Asia were destroyed. Even Asian countries not directly involved in the war were not able to compete in the international market due to the lack of technological advances in their manufacturing industries. As a result, the only nation left to lead the world in manufacturing was the United States. American manufacturers understood this opportunity and become the undisputed mass production leaders of the world.

From the 1940s to the 1960s, American manufacturers enjoyed a period of prosperity. During this time, mass production was emphasized, but quality was not much of a concern for many manufacturers. In the middle 1960s, a few foreign countries started to compete with American products in the international and U.S. markets. This trend continued so that by the 1970s and 1980s, the United States was beginning to "look like an economic colony of Japan" (Wight, 1984, p. 9). American manufacturers were forced to look critically at their cost structures. During the oil embargo and inflation cycle of the 1970s, American manufacturing firms recognized the need to reduce waste and control costs.

One way for the manufacturing industry to stay competitive was to reduce total costs, focusing particularly on inventory and inventory-related costs. That is the goal of
the production planning and control (PP&C) system, which is one of the most critical activities in the manufacturing environment (Vollmann, Berry, & Whybark, 1988). Proper use of PP&C methods can give organizations a competitive advantage in the global economy (Bai & Tsai, 1994). Hopp and Spearman (1996) suggest a hierarchical planning framework of production planning and control. Their framework is divided into three basic levels, as depicted in Figure 1: (a) strategy (long-term planning), (b) tactics (intermediate-term planning), and (c) control (short-term planning).

Evolution of the Production Planning and Control Systems

Before the development of computer technology, production planning and control functions were mainly accomplished manually. Some of the common techniques used were the two-bin system, economic order quantity (EOQ), and reorder point (Gilbert & Schonberger, 1983).

During the 1960s, when computers began to be used in the manufacturing industry, the material requirement planning (MRP) technique was developed by Joseph Orlicky (Taylor, 1994). MRP is a tool used for material and priority planning, the basic function of an MRP system is to plan for material requirements based on planned production levels. The remarkable growth in computing power, along with the reduction in the size and price of computers, allowed for the accelerated implementation of MRP in the United States. This system was considered to be far superior to the older reorder point systems (Orlicky, 1975; Wight, 1974), and it became a phenomenal success. Organizations that implemented the MRP technique increased their inventory turnover per year by more than 100% compared with more traditional production planning and control methods (Hall, 1983). MRP has been used in America since the 1970s,

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
and now the number of companies who employ MRP is in the hundreds of thousands. More than 100 software companies are engaged in the development of MRP software (Das, 1995).

Even though manufacturers derived many benefits from MRP, some limitations were inherent in the technique. MRP ignored very dynamic elements of the shop-floor environment such as capacity limitations and lead time (Berry, Schmitt, & Vollmann, 1982; Schmitt, Berry, & Vollmann, 1988). Lambrecht and Decaluwe (1988) suggest at the operational level of MRP, many batch sizing and timing decisions are “push” in nature because they are created using fixed planning parameters. Many new modules were added to the original MRP system to minimize these limitations. In the early 1970s a new version of MRP, called manufacturing resource planning (MRP II), was introduced as a more comprehensive, system-wide production planning and control technique. Many new modules were also added in MRP II, but it was still a push system. The problems inherent in MRP stem from the failure to reconcile the differences between pull and push elements in production control systems (Veral, 1995). This underlying condition within the MRP environment has caused many difficulties for a large number of organizations striving to meet ever-changing customer demands.

While Western manufacturers were engaged in developing MRP and MRP II, Japanese organizations were formulating their own production planning and control methods. The just-in-time (JIT) concept emerged from the study of the Japanese automobile industry during the 1970s (Spencer, 1992). JIT is based on the philosophy of eliminating any activities that do not add value. Its goal is to get the material to its next processing station just at the time it is needed (Amerine, Ritchey, Moodie, & Kmec,
1993), in the interests of minimizing the inventories for raw material, work-in-process, and finished goods.

Another production planning and control approach, developed by an Israeli physicist Eli Goldratt in the late 1970s, is the theory of constraints. The concept of theory of constraints has subsequently evolved to become known as constraints management (Spencer & Cox, 1995), and this more contemporary term is used hereafter. Constraints management CM is a set of management principles that help to identify obstacles in achieving the goal of an organization and to establish the changes necessary to remove those obstacles. CM recognizes that the strength of any chain is dependent upon its weakest link, which is what restrains the system's throughput. CM assumes that the goal of manufacturing organizations is to make (more) money now and in the future, and describes three avenues to achieve this goal: (a) increase throughput, (b) reduce inventory, and (c) reduce operating expense.

There seems to be no one right production planning and control system for all manufacturing problems. For some organizations, MRP and MRP II work well; for others JIT or CM are better choices. Deciding which production planning and control system to implement can become time consuming yet difficult to implement for only a "trial period."

These three techniques, MRP, JIT, and CM, are the most commonly used in manufacturing today. However, they are not interchangeable: one system may be appropriate for a particular manufacturing situation but not for another.
Statement of the Problem

Because no single production planning and control (PP&C) technique is suitable for all situations, deciding which system to implement can become time consuming. Yet implementing one for a trial period can be costly and difficult. A technology is needed that can employ various types of PP&C methodologies and generate the optimal production plan.

This research is an extension of a previous unpublished study (Choudhry, 1998), which investigated the PP&C methods being used at a midwestern manufacturing organization involved in the production of agriculture equipment. The current research study identified the constraints inherent in the production planning and control system, and based on these constraints, developed and validated a master production scheduling and sequencing optimization model based on constraints management and utilizing genetic algorithms.

Statement of the Purpose

As noted earlier, production planning and control are among the most critical activities in manufacturing. The expected results of this research will allow manufacturing organizations to maximize the effectiveness of PP&C methods, thereby improving their competitive position in the global economy. To that end, the goal of this research is to develop an optimization model based on constraints management and genetic algorithm to address the constraints in the PP&C methods being used at the factory under study.
This research, based on an analysis of five areas of PP&C (master production scheduling, priority planning, capacity planning, priority control, and capacity control), identifies the constraints in that system, and develops and validates master production scheduling and sequencing optimization model based on constraints management and genetic algorithm. The specific objectives of this research were as follows:

1. Identify the system’s constraint.
2. Develop a scheduling and sequencing model to address the identified constraints.
3. Develop and validate the proposed model by simulation using GPSS/H and PROOF, products of the Wolverine Software Corporation located in Annandale, Virginia. GPSS/H is a simulation language, and PROOF is a animation software used within Excel file format.
4. Identify and document improvements attributed to the operational change resulting from the implementation of the optimization model.

**Importance of the Research**

Which production planning and control technique or methodology is best for a company? This question has puzzled many managers in the past. The three main production planning and control systems are material requirement planning, just-in-time, and constraints management. According to Aggarwal (1985), MRP, JIT, and CM are the three most popular management philosophies in current use. There is no consensus between academicians and practitioners as to which approach is best. According to Spencer (1992), “the three techniques are, to a degree, somewhat mutually exclusive.
There appears to be a need to study the three systems in a framework in which their characteristics and behaviors can be examined in detail" (p. 5). These three techniques are discussed in more detail later in this chapter.

Aggarwal reports in his 1985 article:

During the last 15 years, three important approaches—material requirement planning (MRP), kanban (JIT), and optimized production technology (OPT)—have invaded operations planning and control in quick succession, one after the other. Each new system has challenged old assumptions and ways of doing things....factory managers must decide which approach to adopt to meet current and future needs. Installing any one requires several years to train company personnel and millions of dollars of investment. (p. 99)

Most organizations don’t have the resources to try out a method before making a final choice; therefore the managers are left with the grave decision of which one to use.

According to Goldratt and Fox (1986):

The Western manager is challenged to solve a very fundamental problem from this alphabet soup of solutions. To understand each of these new technologies can, by itself, be a time-consuming challenge. Deciding which is best is a formidable task. Figuring out how to put them all together seems beyond our reach. Since we don’t have the time, resources or funds to do everything, everywhere, we had better be convinced that we are taking the actions that will leapfrog us back into the race. There is no longer margin for error and no time for risky experiments. (p. 16)

There needs to be a better way of selecting and implementing a production planning system.

This research can assist practitioners who are trying to learn more about the three techniques. The advantages and disadvantages of each management philosophy, as well as problems that might arise during or after implementation, are discussed by examining one company’s experiences in an in-depth case study. The developed scheduling model

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
for optimization, presented after this discussion, could be used in various manufacturing environments.

**Research Questions**

The previous unpublished study (Choudhry, 1998) focused on the PP&C methods then in use at an engine manufacturing plant (EMP) of a midwestern manufacturer of agricultural equipment. Methods for master production schedule, production priority, and production capacity were explored and documented. Problems in planning and controlling master production schedule, production priority, and production capacity were also identified and documented. The findings of this study are summarized in chapter II.

The current research addresses the following questions. The findings are reported in chapter IV.

1. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the cycle time for the final assembly line and four downstream processes at an engine manufacturing plant (EMP) of a midwestern manufacturer of agricultural equipment (MMAE)?

2. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the queue size for the final assembly line and four downstream processes at EMP?

3. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the utilization of work centers in the final assembly line and four downstream processes at EMP?
4. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the flow rate of engines through the final assembly line and four downstream processes at EMP?

5. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the total output of engines through the final assembly line and four downstream processes at EMP?

Guide (1992) collected and analyzed time in system (cycle time) and work-in-process levels (queue size, inventory levels) to determine if synchronous manufacturing principles produced improved performance in comparison with current production planning and control methodology at a Naval Aviation depot. Taylor (1994) also uses some of these performance measurements to compare the three work-in-process inventory control systems: MRP, JIT, and CM. Performance measurements analyzed by Taylor were: inventory (queue size), throughput (total output of engines), lead time (cycle time), and utilization (utilization of work centers). Manoharan (1997) analyzed total system output (total output of engines), flow time (flow rate of engines), and WIP inventory (queue size) to evaluate the performance of two manufacturing systems, JIT and CM.
Assumptions

The following assumptions were made in pursuit of this research study:

1. That Microsoft Excel is the common production planning tool utilized by various facilities within the total organization.

2. That the production planning and control methods stay the same during the course of this research study at the manufacturing facility under study.

Limitations

This research study was conducted in view of the following limitations:

1. This model was developed in Microsoft Excel and will only work in an Excel environment.

2. For optimization, this research utilizes genetic algorithm-based Evolver software developed by Palisade Inc. This model is limited in application within an Evolver environment.

Definition of Terms

The following terms are defined to clarify their use in the context of this research study.

- Capacity planning: The process of determining the amount of capacity to produce in the future. This process may be performed at an aggregate or product-line level (resource planning), or at the master-scheduling level (rough-cut planning), at the detailed or work-center level (capacity requirements planning). (Cox, Blackstone, & Spencer, 1995, p. 11)

- Capacity control: "The process of measuring production output and comparing it to the capacity plan, determining if the variance exceeds pre-
established limits, and taking corrective actions to get back on plan if the limits are exceeded” (Cox et al., 1995, p. 11).

- Flow rate: As defined in the APICS Dictionary, “running rate; the inverse of cycle time” (Cox et al., 1995, p. 33). Flow rate is also defined by number of units per shift or per hour.


- Just-in-time (JIT): A philosophy of manufacturing based on planned elimination of all waste and continuous improvement of productivity. It encompasses the successful execution of all manufacturing activities required to produce a final product, from design engineering to delivery and including all stages of conversion from raw material onward. The primary elements of zero inventories are to have only the required inventory needed; to improve quality to zero defects; to reduce lead times by reducing setup times, queue lengths, and lot sizes; to incrementally revise the operations themselves; and to accomplish these things at minimum cost. (Cox et al., 1995, p. 42)

- Material Requirements Planning (MRP): A set of techniques that use bill of material data, inventory data, and the master production schedule to calculate requirements for materials. It makes recommendations to release replenishment orders for material. Further, because it is time-phased, it makes recommendations to reschedule open orders when due dates are not in phase. Time-phased MRP begins with the items listed on the MPS and determines (a) the quantity of all components and materials required to fabricate those items and (b) the date that the components and materials are required. Time-phased MRP is accomplished by exploding the bill of material, adjusting for inventory quantities on hand or on order, and offsetting the net requirements by the appropriate lead times. (Cox et al., 1995, pp. 49-50)

- Master production schedule (MPS): The anticipated build schedule for those items assigned to the master scheduler. The master scheduler maintains this schedule, and in turn, it becomes a set of planning numbers that drives
material requirements planning. It represents what the company plans to produce in specific configurations, quantities, and dates. The master production is not a sales forecast that represents a statement of demand. The master production schedule must take into account the forecast, the production plan, and other important considerations such as backlog, availability of material, availability of capacity, and management policies and goals. (Cox et al., 1995, p. 49)

- Priority control: "The process of communicating start and completion dates to manufacturing departments in order to execute a plan. The dispatch list is the tool used to provide these dates and priorities based on the current plan and status of all open orders" (Cox et al., 1995, p. 63).

- Priority planning: "The function of determining what material is needed and when. Master production scheduling and material requirements planning are elements used for the planning and re-planning process to maintain proper due dates on required materials" (Cox et al., 1995, p. 63).

- Theory of constraints, now known as constraints management (CM): A management philosophy developed by Dr. Eliyahu M. Goldratt that can be viewed as three separate but interrelated areas—logistics, performance measurement, and logical thinking. Logistics include drum-buffer-rope scheduling, buffer management, and VAT analysis. Performance measurement includes throughput, inventory and operating expense, and the five focusing steps. Thinking process tools are important in identifying the root problem (current reality tree), identifying and expanding win-win solutions (evaporating cloud and future reality tree), and developing implementation plans (prerequisite tree and transition tree). (Cox et al., 1995, p. 85)
CHAPTER II

REVIEW OF LITERATURE

To understand the nature of the ever-changing manufacturing production environment, we need to develop a common set of functions that are not only unique to production itself but can be generalized to all production organizations (Cox & Spencer, 1998). This research is organized around five functions common to production planning and control. These five functions are master production schedule (MPS), priority planning, capacity planning, priority control, and capacity control. According to Cox and Spencer (1998), the origin of the five production planning and control functions is unclear, but the first source of written reference appears in Oliver Wight’s 1984 book, *Manufacturing Resource Planning (MRP II): Unlocking American Productivity Potential*.

The purpose of production planning and control (PP&C) is to plan and control the production process with regard to time and quantity. According to Corsten and May (1996, p. 69), for the PP&C function, the following four questions have to be answered:

- Which products and parts are to be produced and what is their quantity level?
- Which parts are to be delivered by the supplier in what quantity and when?
- Which capacity utilization results from the master production schedule and how can a capacity adjustment take place?
- In what sequence are the production orders to be worked off and at which workstation?

This chapter provides a review and analysis of the literature related to material requirements planning (MRP), just-in-time (JIT), constraints management (CM), and genetic algorithms (GA) and discusses how each relates to five functions common to production management.
Material Requirements Planning

Evolution

MRP is a tool used for material and priority planning. The basic function of an MRP system is to plan for material requirements based on planned production levels. Wight (1984, p. 47) suggests that MRP tries to answer the following fundamental manufacturing questions:

- What are we going to manufacture?
- What does it take to make it?
- What do we have in our inventory?
- What do we have to acquire?

These fundamental questions, used throughout the manufacturing industry, serve to generate a list of parts needed for the next month in order to avoid part shortages. From this informal system, a powerful one has evolved called material requirements planning. “MRP is simply the logic of the informal system – the shortage list – developed into a formal scheduling system” (Wight, 1984, p. 47).

Although MRP has been in practice informally for many decades in the manufacturing industry, the first published work that formally discussed MRP was Material Requirements Planning, written by Joseph Orlicky in 1975. In his book he states:

In some rudimentary form, MRP has no doubt existed as long as manufacturing. It has been evolving gradually, moving onto successively higher plateaus with every enhancement in data processing capability. MRP had its origin on the firing line of a plant. It has been painstakingly developed into its present stage of relative perfection by practicing inventory managers and inventory planners. (p. 38)
Eventually MRP developed into an overall system called closed loop MRP. Figure 2, is a schema of a closed loop MRP system. The production plan establishes production volumes for product families. The master schedule takes the production plan in units for product families and breaks it down into component parts. Material requirements planning looks at the parts in inventory and determines what component parts are needed to accomplish the production plan. The capacity requirements plan determines the standard hour requirements for the production plan. Once planning for material and capacity requirements is completed, it must be determined if the plans are realistic. If they are realistic, then both material and capacity plans need to be monitored to ensure that the plans are being executed.

Despite the formalization of the MRP system, its limitations were still confining to the organization’s ability to perform better production planning and control functions. Finance, a big piece of the puzzle, was still missing in the closed loop MRP; financial systems were not tied to the closed loop MRP. In the 1970s, manufacturing resource planning (MRP II) evolved out of the closed loop MRP, tying the financial system to the operating system. As Wight (1984, p. 49) noted, “tying the financial and the operating systems together was the big step from closed loop MRP to MRP II.” Figure 3 is a schema of an MRP II system.
Figure 2. Closed loop MRP.
Figure 3. Manufacturing resource planning (MRP II).
Functionality

MRP deals with end-items (finished products) and the component parts (lower level items) that make up the end items. The bill of material (BOM) connects the end items with the lower level items. Figure 4 illustrates a typical bill of material for the end-item X. To facilitate the MRP processing, each component part in the bill of material is assigned a low level code (LLC). The LLC indicates the lowest level for which a part is used in a bill of material. In the following figure, the end item X has an LLC of 0. The component parts 10 and 20 have an LLC of 1, parts 30, 40, and 50 have an LLC of 2; and part 60 and 70 an LLC of 3.

Figure 4. A typical bill of material (BOM).
Table 1 illustrates the material requirements plan for Part A. The gross requirements for Part A come from the production plan. Schedule receipts are the orders that are already in production. To calculate when an order needs to be placed, gross requirements are subtracted from the available balance and schedule receipts are added to it. In Table 1, for example, the on-hand balance is 400 units, the gross requirements for Week 1 are 120 units, so the projected on-hand balance for Week 1 is 280 units. The first uncovered demand in this example is in week 8 for 60 units. The lead time for Part A is 4 weeks; therefore, the order needs to be placed in Week 4 to cover the demand of 60 units in Week 8. The example above illustrates a simple MRP procedure. Because of space constraints, full discussion on the components of MRP procedure—netting, lotsizing, offsetting, and BOM exploding—is not covered in this research. For a full discussion of MRP, see Wight (1984) or Hopp and Spearman (1996).

Table 1

<table>
<thead>
<tr>
<th>Time-Phased MRP Requirements Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Part A</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Week</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>120</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>Planned order releases</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Advantages and Disadvantages

In the late 1960s and early 1970s, with the rapid advancement in computer technology, MRP took over the manufacturing industry. “Starting in the sixties and on into the seventies, the basic elements of an integrated production planning and control system known as MRP, were established” (Taylor, 1994, p. 8). Initially, computer-based MRP was thought to be so powerful that it made the classical methods of inventory management obsolete. One of the major advantages of the MRP system is its adaptability to dynamic changes and the ability to know what is required several periods in advance (Nagendra, 1995).

Many success stories are reported in the literature about MRP. According to Aggarwal (1985), MRP has indeed helped many organizations in the effort to reduce inventories and streamline scheduling. In discussing the advantages of MRP, Orlicky (1975) notes,

this subject, broadly viewed, marks the coming of age of the field of production and inventory control, and a new way of life in the management of manufacturing business. In the area of manufacturing inventory management the most successful innovations are embodied in what has become known as the material requirements planning (MRP) system. (p. 4)

Umble and Srikanth (1990) state, “MRP became a crusade that helped to shift the emphasis away from the traditional ‘just-in-case’ inventory mentality and toward a manufacturing control system based on actual need dates and quantities” (p. 8).

Manufacturing organizations around the world invested billions of dollars and human resources in the implementation of MRP. In the United States alone, by 1989, sales of MRP software and support exceeded one billion dollars (Hopp & Spearman, 1996), but not all of the outcomes were successful. Taylor (1994), in summarizing the
findings of Anderson, Schroeder, Tupy, and White (1982), reports that a great number of the firms that attempted MRP implementation were not always satisfied. According to Rice and Yoshikawa (1982), the weakest MRP area is in capacity planning. Nagendra (1995) also reports the inability of MRP to perform comprehensive capacity planning. Ashton, Johnson, and Cook (1990) likewise note part-shortage problems that disrupt operations due to MRP. Cox and Clark (1984) report other technical problems such as inventory management and infinite capacity assumption.

MRP has to be constantly modified to cope with the changing manufacturing environment. Over the years, many modules have been added to MRP giving it the more deserved name of manufacturing resource planning (MRP II). With MRP II, manufacturing interacts with other functions of the organization, such as accounting, finance, and human resource planning.

MRP has been an effective tool for several decades for many organizations, even with its built-in limitations. With the changing business environment, production planning and control methods also need to be changed. MRP-based production planning and control solutions are appropriate for organizations with repetitive manufacturing. However, the advantages of MRP for high-mix, low-volume manufacturing organizations are very limited.
Just-in-Time

Evolution

Even though the elements of just-in-time (JIT) has been around since the 1900s, the American manufacturing industry did not start paying serious attention to it until the late 1970s. "The first records of the JIT management philosophy stem from the efforts of Henry Ford and his assembly line operations" (Taylor 1994, p. 13). JIT received much attention in the Western manufacturing world during the early 1980s when a large number of books and articles were written on this subject. Between 1970 and 1991, more than 860 articles about the just-in-time philosophy were published in professional journals (Golhar & Stamm, 1991). The JIT system has become extremely popular in recent years and has been implemented in many kinds of companies around the world.

The just-in-time philosophy is based on the work of Taiichi Ohno of the Toyota Motor Company (Sugimoro, 1977). In the early 1980s, many American manufacturers regarded JIT as a Japanese manufacturing philosophy suited only for Japanese organizations. Initially, most Westerners viewed it as an inventory reduction system, beneficial only for large repetitive manufacturers (White, 1993). As more and more Western organizations successfully applied JIT principles, its benefits became evident for a wide range of manufacturing environments (Hall, 1983). U.S. managers also became more knowledgeable of JIT and described it as a holistic management approach consisting of various practices that contribute to the elimination of waste and a philosophy of continuous improvement of a manufacturing system (Hall, 1987; Schonberger, 1986; White, 1993). Today, many American manufacturing companies regard JIT as vital to their survival (Hobbs, 1997).
Functionality

The JIT philosophy is based on the concept of the elimination of waste in the system. JIT's purpose is to minimize in-process and final inventories (Hall, 1983; Monden, 1983). Early academic research focused on utilizing JIT systems within the internal manufacturing environment (Spencer, Daugherty, & Rogers, 1996), but this approach to JIT is evolving toward a broader concept—a total business philosophy. According to Ramasesh (1992), "JIT represents an integrative philosophy of operations which encompasses several functional systems both within the firm and outside of the firm" (p. 44).

Hall (1983), Sage (1984), and Heard (1984) all agree that the JIT philosophy is based on the pull method of production called “kanban.” According to the APICS Dictionary (Cox et al., 1995), kanban is a “method of Just-In-Time production that uses standard containers or lot sizes with a single card attached to each. It is a pull system in which work centers signal with a card that they wish to withdraw parts from a feeding operation supplier” (p. 42). The APICS Dictionary defines pull system as “the production of items only as demanded for use, or to replace those taken for use. In material control, the withdrawal of inventory as demanded by the using operations. Material is not issued until a signal comes from the user” (p. 68).

Advantages and Disadvantages

One of the main advantages of JIT is its emphasis on shop-floor control rather than inventory control (Ohno, 1982). Im and Lee (1989) and Burnham (1987) report many benefits derived from the successful implementation of JIT, including improvements in production planning, improvements in MPS and MRP, and reduction in
inventory. A study conducted by Gilbert (1990), of 250 American manufacturing organizations, found significant reduction in the investment of inventory associated with the implementation of JIT. Other benefits reported by researchers included reduced throughput time, improved labor productivity, improved quality, decreased inventory levels, and reduction in space required for operations (Celley, Clegg, Smith, & Vonderembase, 1986; Golhar, Stamm, & Smith, 1990; Hay, 1988).

Reducing inventory levels toward zero requires eliminating variability within a system. It is very difficult, if not impossible, to eliminate all the variability from a complex manufacturing system. To tackle this problem, managers on the shop floor would have to increase buffer size, which, in turn, would increase the work-in-process inventory. However, this goes against the JIT philosophy. According to Rice and Yoshikawa (1982), the weakest area in JIT is master production planning.

Another drawback is the time required for implementing JIT (Schonberger, 1986). For most Western organizations, the JIT implementation process spans many tedious years. Umble and Srikanth (1990) report four major limitations inherent in JIT and kanban:

First, the number of processes to which JIT logistical systems such as kanban may be successfully applied is limited. Second, the effects of disruptions to the product flow under the kanban system can be disastrous to current throughput. Third, the implementation period required for JIT/kanban systems are often lengthy and difficult. Fourth, the process of continuous improvement inherent in the JIT approach is system wide and therefore does not focus on the critical constraints, where the greatest gain is possible. (p. 125)
Overall, the just-in-time approach to PP&C is based on the philosophy of elimination of all waste in the system. Organizations around the world have been implementing JIT for the last few decades and many of them have reported numerous benefits (Bartezzaghi & Turco, 1989; Burnham, 1987; Crawford, Blackstone, & Cox, 1988; Im & Lee, 1989). Even though there are some drawbacks to implementing JIT, organizations can gain competitive advantage once it is accurately implemented.

Constraints Management

Evolution

Originally known as theory of constraints, constraints management was developed at about the same time as the just-in-time philosophy started to make an impact on Western organizations. Goldratt developed an optimized production timetable (OPT) to assist a friend in the production and assembly of prefabricated chicken coops (Jayson, 1987). The OPT schedule enabled the producer to triple his production without increasing any human resources (Taylor, 1994). The logic behind the OPT software was not revealed because of proprietary reasons. Contrary to MRP philosophy, OPT assumes that production capacity is finite, restricted by the bottleneck operation (Dugdale & Jones, 1995). According to Nahmias (1989), OPT follows these nine principles:

1. Balance the flow, not the capacity.
2. The level of utilization of the non-bottleneck resource is determined not by its own potential, but by some other constraints in the system.
3. Utilization and activation of a resource are not synonymous.
4. One hour lost at the bottleneck operation is an hour lost for the total system.
5. An hour saved at the bottleneck is a mirage.
6. Bottleneck operations govern both throughput and inventory in the system.
7. The transfer batch might not, and many times should not, be equal to the process batch.
8. The process batch should be variable, not fixed.
9. Schedules should be established by looking at all of the constraints simultaneously. Lead times are the result of a schedule and cannot be predetermined. (p. 13)

According to Taylor (1994), constraints management was originally known as OPT, when it was first formulated in 1979. In 1982, the name was changed to optimized production technology, in 1984 to synchronous manufacturing, 1987 it became theory of constraints, and recently it became constraints management.

CM was originally regarded as a management technique suitable for the shop floor, but eventually it was used to manage and solve problems that extended far beyond that (Hobbs, 1997). CM applies the methods of science to the general problem of management (McMullen, 1997). Rack and Rack (1993) define it as follows:

a thinking process used to analyze problems, create or choose appropriate solutions and get buy-in to achieve successful results. Although it is demonstrably very powerful, it is not difficult to understand. Because the process utilizes how man was designed to think, it works for almost everyone interested in tapping into his/her own abilities. The appropriate use of the thinking process significantly impacts the goal and is intrinsically rewarding to the one(s) using it. (p. 3)

Functionality

The main focus of the CM approach is to concentrate effort on the system's constraint(s). Goldratt (1990a) emphasized this point by addressing the need of focusing on a small portion of the system at a time. He went on to say, “spreading attention equally to all portions of the area means no concentration whatsoever, no focusing” (p. 58).

CM methodology is based on five focusing steps:

1. Identify the system constraint(s).
2. Decide how to exploit the system's constraint(s).

3. Subordinate all else to the constraint(s) of the system.

4. Elevate the system's constraint(s).

5. If, in step 4, the constraint has been broken, go back to step 1, do not let inertia become the system's new constraint.

A constraint is anything that limits the organization's achievement of its goal. If the scarce resources of an organization can be used to elevate the system's constraint(s), the organization's goal, which is to make money now and in the future, can be achieved successfully. Goldratt (1994) suggests that the five focusing steps follow a framework based on the following questions:

1. What to change (finding the core problem)?

2. What to change to (devise simple, practical solutions)?

3. How to cause the change (cause others to invent or discover the ideas)?

"The three elements of change are techniques for verbalizing our intuition so we can check its soundness and communicate it clearly to others" (Taylor, 1994, p. 21).

Goldratt has developed approaches to deal with problems using the Socratic method, rather than the more traditional Aristotelian way. According to Taylor (1994), Goldratt developed the following techniques to deal with change:

1. Effect-cause-effect: A technique for finding the core problem. This method allows for verbalization of intuition and its cause.

2. Evaporating clouds: A technique for stating a problem as a conflict. This allows for the conflict assumptions to be challenged. Faulty assumptions allow the problem to disappear.
3. Socratic method: This allows for others to invent or discover answers themselves and conceive ownership in them. According to Woeppel (1991), all of the above techniques have proven to be very effective for increasing one's ability to verbalize intuitively. These techniques have been used in the manufacturing industry to develop and implement effective procedures.

Constraints management also addresses the issue of inventory in process with drum-buffer-rope (DBR) technique, defined by the APICS Dictionary as "the generalized technique used to manage resources to maximize throughput. The drum is the rate or pace of production set by the system's constraint. The buffers establish the protection against uncertainty so that the system can maximize throughput. The rope is a communication process from the constraint to the gating operation that checks or limits material released into the system to support the constraint" (Cox et al., 1995, p. 25).

CM emphasizes the need of inventory buffer in front of the constraint operation. DBR concentrates on managing the flow of products to meet the bottleneck constraint's needs. The buffer inventory in front of the constraint protects the constraint from stockouts due to upstream process interruptions. Since the bottleneck acts as a valve controlling the system's throughput, managing the bottleneck's throughput manages the system's throughput. To maximize the system's throughput, the bottleneck must utilize all of its available capacity.

The three commonly used PP&C methods discussed MRP, JIT, and CM, all offer some advantages for organizations engaged in various types of manufacturing activities. To choose any one of these three PP&C methods and apply it for all types of manufacturing environments would not be an easy task, especially for managers with
little exposure to academic research. The present research would help managers in repetitive industry to compare and evaluate the three popular PP&C approaches and choose the one that would work best for their manufacturing environment. The next section discusses genetic algorithms, the history and functionality.

Genetic Algorithms

Genetic algorithms are becoming a widely used tool for difficult optimization problems (Bennett, Ferris, & Ioannidis, 1991; Goldberg, 1989; Grefenstette, 1987). In recent years, GA have received remarkable attention all over the world, a fact reflected in the amount of literature published on this topic in the last few years (Back, 1996). Researchers have explored the possibilities of GA applications in various fields, including game theory, process planning, classifier systems, machine learning, and function optimization (Crossley, 1995). The use of GA for scheduling in manufacturing has also been explored by many researchers (Bagchi, Uckun, Miyabe, & Kawamura, 1991; Davis, 1985, 1991; Nissen, 1993; Whitley, Starkweather, & Fuquay, 1989).

History

The history of genetic algorithms goes back more than four decades (Back, Hammel, & Schwefel, 1997). Bremermann (1962, 1967, 1968, 1973), Fraser (1957, 1962, 1968), Reed, Toombs, and Barricelli, (1967), and Holland (1969, 1975) report early research related to genetic algorithms. Genetic algorithms in the present form were developed by Dr. John Holland, computer scientist and psychologist at the University of Michigan. Dr. Holland, along with his students and colleagues during the 1960s and 1970s, developed the research area of artificial intelligence (AI), now known as genetic
algorithms. His book Adaptation in Natural and Artificial Systems (1975) is considered to be the starting point of almost all known applications and implementations of genetic algorithms (Back, 1996).

Research in the field of artificial intelligence is based on the idea that “evolution could be used as an optimization tool for engineering problems” (Mitchell, 1996, p. 5). The common theme in almost all evolutionary systems is the belief that it is possible to evolve a population of candidate solutions to a given problem, using operators inspired by natural genetic variation and natural selection (Chambers, 1991). Many researchers have expanded on Holland's research on genetic algorithms since 1975.

The growing complexity of scheduling and sequencing problems in manufacturing has led many researchers to experiment with genetic algorithms as an optimization tool. Genetic algorithms have been used to solve scheduling problems with increasing frequency since the early 1980s. Various researchers (Bagchi et al., 1991; Cleveland & Smith, 1989; Davis, 1985; Nakano & Yamada, 1991; Syswerda, 1991; Whitley et al., 1989) have reported experimentation with genetic algorithms to solve scheduling problems.

Functionality

The genetic algorithm is a probabilistically guided search method, “developed originally in the 1970's as a computer science tool to improve programming structures and performance” (Holland, 1992, p. 66). Chambers (1991) defines GA as a “problem solving method that uses genetics as its model of problem solving” (p. 13). GA are search techniques based on the mechanics of natural selection and genetics, and they involve a structured yet randomized information exchange resulting in the survival of the
fittest amongst a population of string structures. GA operates on a population of structures that are fixed-length strings representing all possible solutions to a problem domain (Mars, Chen, & Nambiar, 1996). Genetic algorithms work by mimicking the “survival of the fittest” patterns of natural selection and reproduction similar to those in biological populations (Crossley, 1995).

Davis (1991) identifies four features of the evolution process that are the bases of genetic algorithms. These four features are as follows:

1. Evolution is a process that operates on chromosomes rather than on living beings they encode.
2. Natural selection is the link between chromosomes and the performance of their decoded structures. Process of natural selection causes those chromosomes that encode successful structures to reproduce more often than those that do not.
3. The process of reproduction is the point at which evolution takes place. Mutation may cause the chromosomes of biological children to be different from those of their biological parents, and recombination processes may create quite different chromosomes in the children by combining material from the chromosomes of two parents.
4. Biological evolution has no memory. Whatever it knows about producing individuals that will function well in their environment is contained in the gene pool the set of chromosomes carried by the current individuals—and in the structure of the chromosome decoders. (pp. 2-3)

The features described above allow genetic algorithms to solve complex problems without having any knowledge of the problem or the search space. Michalewicz (1994) identifies five components that must be contained by genetic algorithms:

1. A genetic representation for potential solutions to the problem
2. A way to create an initial population of potential solutions
3. An evaluation function that plays the role of the environment, rating solutions in terms of their fitness
4. Genetic operators that alter the composition of children
5. Values for various parameters that the genetic algorithm uses. (p. 6)
The three basic operators that are found in every genetic algorithm are (a) reproduction, (b) crossover, and (c) mutation.

**Reproduction.** The reproduction operator permits individual strings to be copied in the next generation. The string’s chance to be copied to the next generation depends on its fitness value calculated from a fitness function. The reproduction operator chooses strings that were placed in the waiting pool for each generation. The next generation is based on this pool.

Table 2 demonstrates that string 01100 is the best fit. This string should be selected for reproduction approximately 66% of the time. String 01101 is the second best fit and should be selected 21% of the time. And string 10101, the weakest, should be selected only 13% of the time.

**Table 2**

**Fitness Test**

<table>
<thead>
<tr>
<th>String</th>
<th>Fitness value</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>01101</td>
<td>8</td>
<td>21</td>
</tr>
<tr>
<td>10101</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>01100</td>
<td>25</td>
<td>66</td>
</tr>
</tbody>
</table>

**Crossover.** After the mating pool is created through the selection operator, the next genetic algorithm operation is called crossover. In biological terms, crossover
occurs when two parents exchange parts of their corresponding chromosomes to produce an offspring. Figure 5 illustrates the crossover operation within genetic algorithms.

\[
\begin{align*}
\text{Parent 1:} & \quad 1 & 0 & 1 & 1 & 1 \quad \text{Child 1:} & \quad 1 & 0 & 1 & 1 & 0 & 0 \\
\text{Parent 2:} & \quad 0 & 1 & 0 & 0 & 0 \quad \text{Child 2:} & \quad 0 & 1 & 0 & 0 & 1 & 1 \\
\end{align*}
\]

**Figure 5.** Crossover operation.

Each child in the example receives four of the six parts of each parent’s genetic material. In a genetic algorithms search, crossover is performed until a new population is created, and then the cycle starts again with a new selection. According to Davis (1991), crossover is an extremely important component of a genetic algorithm. Use of the crossover operator distinguishes the genetic algorithm from all other optimization algorithms.

**Mutation.** The mutation operator brings a certain amount of randomness to the genetic search. Mutation can help the genetic search to find solutions that crossover alone might not encounter. Selection and crossover operations in a genetic search can generate a large quantity of different strings. However, depending on the initial population of the search, the resulting strings may not have enough variety. The mutation operator can offset this shortcoming. When a genetic algorithm performs a mutation, it randomly changes the element value to a new one. If, to use the example in Figure 5, Position 5 of the Parent 1 string were mutated, the resulting string would be 101101. In the binary strings, 0s are changed to 1s and 1s are changed to 0s.
There are significant differences between genetic algorithms and other optimization tools. Crossley (1995) identifies four major differences between calculus-based optimization and genetic algorithms as follows:

1. GA works with a coding of the design variables and parameters in the problem, rather than with the actual parameters themselves.
2. GA makes use of a population-type search. Many different points are evaluated during each iteration, instead of moving from one point to the next.
3. GA needs only a fitness or objective function value. No derivatives or gradients are necessary.
4. GA uses probabilistic transition rules to find new points for exploration rather than using deterministic rules based on gradient information to find new design points. (p. 24)

One of the most significant advantages of using genetic algorithms is flexibility and adaptability to the problem at hand (Back et al., 1997).

Foundational Study for Current Research

In an earlier study, which provided the basis for the present research, Choudhry (1998) investigated the current status of production planning and control methods at an engine manufacturing plant (EMP) of a midwestern manufacturer of agricultural equipment, hereafter referred to as MMAE. In that study, the writer focused on 11 questions dealing with current methods and problem areas. The results are reported under the following listing of those 11 research questions.

Current Production Planning and Control Methods

1. What are the production planning and control (MRP, JIT, CM) methods currently being used at EMP?

Production planning is the primary responsibility of the logistics manager, who reports directly to the plant manager. The seven employees in the production planning
department include a supervisor of production planning and an employee who performs the daily final assembly scheduling (line-up). Three employees are involved in the distribution of the daily schedule to the shop floor. One employee is responsible for the inventory accuracy, and the seventh employee is in charge of fulfilling service store requirements. The purchasing department orders components based on the master schedule in the MRP and is also responsible for component sourcing and price negotiations.

The key performance measurements for the logistics department were not clear because at the time of this study, the department had only been in existence for a few months. The key performance measurements for the production planning supervisor and the department are (a) due date performance as a percentage of total order shipped (for the three months prior to this study, this figure was close to 100%); (b) customer acceptance; and (c) a target inventory as a percentage of sales.

In late 1979 EMP developed and implemented an in-house material requirements planning system, which has undergone significant modifications throughout the following years. The system continues to be modified at the present time as the need arises. MMAE is in the process of implementing an enterprise resource planning (ERP) system by SAP throughout its plants around the world. At its midwestern locations, this implementation will start in the middle of 2000 and will be fully implemented in about two years.

Accuracy of the bill of material (BOM) is around 96%, and part routing accuracy is 95%. Changes are made daily to the bills of material. Communication seems to be the main problem between the specification and engineering departments. Routings are not
changed frequently, two per part for new engines and about 5% for the repetitive builds. For the inventory management, an ABC analysis was performed, and EMP uses six categories—A, B, C, D, E, and F. A cycle counting system is in operation, which is a physical count of inventory that is conducted every quarter; once a year, auditors from the company corporate office count the inventory. Inventory turns are about 13 per year. Inventory breakdown at EMP is as follows: raw, about 34.4%; WIP, 57.1%; and finished goods, about 8.5%.

The current MRP system is regenerated on a weekly basis and is using weekly buckets for requirements. Daily net changes for the master production schedule and inventory netting are performed. Even though the logistics manager is pleased with the accuracy of the MRP reports, he considers them very time insensitive. In the new global economy, customer requirements are being changed regularly without regard to weekly buckets.

EMP has been relying on the MRP system for production planning and control activities since its implementation in 1979. Some aspects of just-in-time (kanban) are also being implemented in a few subassembly work centers. Constraints management is not being practiced formally, but management does consider the two bottleneck operations in the plant when production planning activities are undertaken. The management at EMP is trying to minimize reliance on MRP. Many new projects are under way to develop Excel-based tools for PP&C.
2. **What methods are currently being employed to develop the master production schedule at EMP?**

The process of master scheduling at EMP begins when an order is received from the customer with the required ship date. For interfactory customers, the common worldwide interfactory system (CWIS) is used; for various original equipment manufacturers (OEM), the complete goods order management and reporting system (COMAR) is utilized. The difference between the two types of orders is that options are attached to OEM orders. Engines built for each OEM customer are unique, whereas engines built for interfactory customers are built via repetitive manufacturing methods.

The master scheduler enters these orders into the master schedule system and accounts for the number of days it takes to build an engine (lead-time). After the leveling activity is completed, information is passed on to a planner to perform the line-up. The same information is entered into the system's material requirements planning (MRP), which in turn passes it to CPS (common purchasing system), so the purchasing department is informed when to procure the parts.

MRP generates the shop production schedule (SPS) for the machining department, informing them when to start production for these parts based on the parameters maintained in MRP (lead-time, scrap %, order policy, etc.) by the planners in the machining department. The planners in the machining department report to the machining business unit leader. MRP information is driven by the line-up for 20 days and the master schedule beyond the 20-day time frame.
If a shortage is foreseen for any parts, the critical shortage report comes into play. When purchasing cannot procure a part or machining cannot manufacture one, that information is generated on the critical shortage report and passed on to a scheduler.

Most of the computer systems used at EMP are "legacy" systems. They were called common systems (MRP, COMAR, etc.) because they were supposed to work in a uniform manner for all MMAE units around the world. If any changes were proposed in the system, those changes had to be approved by a committee consisting of members from each plant. If the changes were approved by the committee, each unit incorporated them into the system. However, in the last few years, this situation has changed. Now each unit makes changes independently. As a result, MMAE does not pay headquarters for system support, and the company is moving toward implementation of an enterprise resource planning system by SAP.

When there are changes to be made in the engineering specification of a particular engine, the product engineering center (PEC) provides this information to the head of the specification department. This department works through the approved specifications and loads them in the system along with the effectivity dates. The information is routed to appropriate departments affected by the changes. If the changes have to do with options for OEM customers, that information also needs to be routed through the marketing department, so they can forecast for parts or options.

Of the engines manufactured at EMP, 85% are sold to interfactory customers, and the rest are sold to OEM customers. These engines are used in tractors, combines, and other agriculture and construction equipment for the interfactory customers. Interactions
with dealers are then minimal; the marketing department, specifically the OEM representative, interacts with OEM dealers and customers.

3. What methods are currently being employed to plan production priority at EMP?

The 85% of engines produced for interfactory customers are manufactured via repetitive build, whereas the rest of the engines, for OEM customers are customized with many options for each model. The MRP process of explosion and netting lose this identity. Production orders for the shop floor are created by the MRP based on the lead times of each component.

Even though MRP creates shop orders for a majority of the manufactured components, EMP has been in the process of establishing kanbans, in this case a replenishment cycle of about two to three days for 80% of the components. Priority planning at EMP is accomplished through the use of the MRP trigger system for purchased components. Kanban is used to plan priorities for 50% of in-house manufactured parts. Management at EMP has initiated projects in the last two months to include all in-house parts for kanban delivery.

The primary priority planning document used for the final assembly line is the report generated manually by the production scheduler titled “daily line-up”. This report lists all engines to be built in the sequence that day, based on customer ship orders. The report is distributed to 60 work centers on the final assembly and subassembly lines. The new logistics manager has initiated many projects to streamline the master scheduling and daily line-up process at EMP. In the new PP&C process, distribution of daily line-up sheets will be either eliminated or minimized. EMP is in the process of implementing kanbans for the majority of the subassembly stations.
4. What methods are currently being employed to plan production capacity at EMP?

Capacity is defined at EMP by the number of engines built per day. Long-term capacity planning occurs during the next fiscal year’s production planning process. Capacity has never been a major issue at EMP. This facility was built to produce 300 engines per day, but demand for engines has never exceeded that number. Production can be easily increased, if the forecast indicates a growth in sales.

EMP operates on two shifts for the final assembly on a five-day-per-week basis; however, it is possible to drop to one shift if the demand declines for a few weeks. Because of the current union contract, MMAE’s four local plants cannot lay off any hourly employees. When production is cut, shop floor employees are put in a “resource pool” which is comprised of extra employees and used for rapid continuous improvement (RCI) projects.

Short-term capacity planning for the assembly areas is accomplished through the use of a final assembly schedule for the following 20 days and a computer program (Workforce & Machine Load) that converts units into the workforce required. Adjustments to the final assembly schedule are rarely made at the final assembly line due to the unavailability of operators.

The test and paint departments are the current constraints at EMP; many times, test and paint problems cause delays in customer shipments. The test and paint departments run on a three-shift, five days/week basis. Only eight test cells must handle about 171 engines per day. Capacity for the paint department is 30 engines per shift, 90 engines per day. About 60% of the engines manufactured at EMP require paint. Capacity is adjusted by adding overtime shifts on Saturdays and Sundays.
5. What methods are currently being employed to control production priority at EMP?

In the final assembly and subassembly areas, priority is controlled by the daily line-up schedule. Once the daily line-up is created for the following three days, unique serial numbers are assigned to each engine, and serial plates and serial tags are generated. If there is a change in the build schedule, the master scheduler has to make manual changes on the distributed line-up sheets. There are about 10 changes per week in the final assembly line-up.

Order changes are established through negotiations between the EMP management and its interfactory and OEM customers. Both types of customers can change their orders in the CWIS beyond 90 days without approval from the master scheduler. If changes are made within 90 days, customers must request the changes through CWIS, which generates an “action file.” The changes in the action file have to be reviewed and accepted by the master scheduler. If EMP cannot fulfill the requirements, the master scheduler proposes a date when those requirements can be fulfilled. This interaction with the customer continues until both parties agree on a mutually satisfactory date. Changes in customer requirements affect 13% of the total sales at EMP.

6. What methods are currently being employed to control production capacity at EMP?

Department supervisors control capacity at the two bottleneck areas, test and trim and paint, on a daily basis along with the assembly general supervisor. Overtime is scheduled as required if production exceeds capacity. Assembly supervisors request overtime authorization from the plant manager. The test and trim department schedules
overtime on a regular basis to avoid any delays in shipping. The new logistics manager has initiated a project to streamline these departments.

Identification of the current methods of production planning and control practiced at EMP was not an easy task. Interviewees often could not describe the current process in place. The researcher had to illustrate and explain the majority of the production planning and control terminology to extract information. In the next section the problems inherent in the current production planning and control system at EMP are presented.

**Problem Areas by Production Function**

1. What problems are currently being encountered in master production scheduling at EMP?

   The first area of concern for management regarding the master production schedule is the reliance on legacy computer systems, CWIS and COMAR. These systems are very labor intensive, requiring too much duplication of work by the master scheduler and the schedulers. A second area of concern is the limitations of the MRP system, which is unable to support changes during the week. Changes in the master production schedule only become apparent after the weekend report is generated by the system. Another concern is the development of the MPS by the master scheduler. According to the master scheduler, no formal procedure is in place for the development of the MPS for the following fiscal year. The master scheduler uses a rolling 12 months for the development of the MPS instead of using a fiscal year.

2. What problems are currently being encountered in planning production priority at EMP?

   The first area of concern is the limitations of the MRP system and the execution of the master production schedule. MRP is limited to weekly buckets, which create
unseen changes made during the week by the master scheduler. Management has implemented controlled delivery for a few subassembly work centers to establish priorities. A final assembly schedule is prepared from the master production schedule and is also used to identify the priorities in machining. The final assembly schedule, which is in weekly buckets, is also used by the scheduler to line-up engines for the next 20 days. The line-up schedule is used to generate the part shortage list, “critical shortage day-one.” Another area of concern is the marketing department’s ability to alter relative production priorities as required for OEM customers. Reprioritization in the final assembly schedule also creates problems for the machining department. A third problem is the long lead-times for three critical parts: turbo, injection pump, and pistons. Lead-time for these parts averages about 120 days. Long lead-times limit the flexibility of MMAE to respond to customer changes in requirements.

3. What problems are currently being encountered in planning production capacity at EMP?

Capacity planning at EMP occurs concurrently with master production scheduling. Long lead-times for component parts is a concern for management. Due to the union contract, there is a long lead-time to change labor capacity relative to the order horizon. Another concern for management is the shut-down days of sister factories. Various interfactory customers plan their shut-down days/weeks according to their own needs. This creates changes in the requirement dates, and the master scheduler has to pull ahead orders and repeat the leveling activity.
4. What problems are currently being encountered in controlling production priority at EMP?

The key area of concern for priority control occurs at the two bottleneck areas: test and paint. Daily monitoring by the department supervisors and the general supervisor of assembly is the control method used for priority control in these areas. In these two departments reprioritization is common to meet customer ship dates. Another concern is the amount of changes in customer orders, which is about 13% monthly. Changes in customer orders can require the reprioritization and expediting of orders to make sure customer delivery dates are met. Frequency of set-up required on the assembly line is also problematic. The set-up frequency and time are factors not taken into considerations in the MRP calculations. Since the early stages of implementation, problems related to kanban have not been addressed by EMP.

5. What problems are currently being encountered in controlling production capacity at EMP?

Changes in available capacity at EMP occur due to machine down-time or changes in customer requirements. Capacity problems are typically resolved by using overtime or reassigning workers to areas where they are needed. Overtime in any assembly area must be approved by the factory manager. Department supervisors adjust workforce assignment, if allowed by the union contract, to resolve capacity problems.

During the course of this research, the logistics manager initiated several projects to address these problems and streamline the production planning process. A number of these projects will take more than a year to make an impact on the current production planning process.
Summary

This chapter examined the literature pertinent to the three most common production planning and control methods: material requirement planning (MRP), just-in-time (JIT), and constraints management (CM). The history, functionality, and advantages/disadvantages of each were discussed. The origin of genetic algorithms, as well as a discussion of the functionality of this method, was presented. One of its most significant advantages, it was pointed out, is flexibility. The findings of a foundational study for the current research, both current production planning and control methods and problems areas by production function, were reported.
CHAPTER III
RESEARCH DESIGN AND METHODOLOGY

Research Design

This experimental research (proposed method/present method) was designed to identify production planning and control (PP&C) constraints and to develop and validate scheduling and sequencing model based on constraints management and using genetic algorithms. The five research questions stated in Chapter I were used as a basis for this study.

1. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the cycle time for the final assembly line and four downstream processes at an engine manufacturing plant (EMP) of a midwestern manufacturer of agricultural equipment (MMAE)?

2. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the queue size for the final assembly line and four downstream processes at EMP?

3. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the utilization of work centers in the final assembly line and four downstream processes at EMP?

4. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the flow rate of engines through the final assembly line and four downstream processes at EMP?
5. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the total output of engines through the final assembly line and four downstream processes at EMP?

**Independent Variable**

The independent variable in this research is the method of scheduling and sequencing. The control condition is the current scheduling and sequencing method, and the experimental condition is the proposed scheduling and sequencing model based on constraints management and utilizing genetic algorithms.

**Dependent Variables**

The dependent variables in this research are as follows:

1. Cycle time of engines for the final assembly line and four downstream processes
2. Queue size in front of four downstream processes after final assembly line
3. Utilization of work centers in the final assembly line and four downstream processes
4. Flow rate of engines through the final assembly line and four downstream processes
5. Total output of engines through final assembly line and four downstream processes
Present Method / Proposed Method

Control Group

The process of master scheduling at EMP begins when an order is received from the customer with the required ship date. For interfactory customers, the common worldwide interfactory system (CWIS) is used; for various original equipment manufacturers (OEM), the complete goods order management and reporting system (COMAR) is utilized.

The master scheduler enters these orders into the master schedule system and accounts for the number of days it takes to build an engine (lead-time) for the next 12 months (Figure 6). Customer orders for the next two months are manually entered in an Excel workbook. These orders are broken down from monthly buckets into weekly buckets for these two months based on the customer due date and percentage of painted engines. An Excel file containing customer orders for the next four weeks is passed on to the line-up scheduler.

Customer orders for the next four weeks are broken down into daily buckets based on the customer due date and percentage of painted engines. A manual check is performed after the daily breakdown operation to confirm the percentage of painted engines is less than 70%. If the daily percentage of painted engines is less than 70% and customer due dates are met, a production build date is assigned to each customer order for the next 20 production days. If the daily percentage of painted engines is greater than 70%, assigned dates are adjusted manually and the schedule is frozen for the next production day. The next day’s frozen schedule is manually sequenced in small batches.
The build schedule is generated and distributed on the shop floor for the next production day.

Flow chart for the control group was reviewed by the key expert in the area of production planning and control at EMP (D. Eck, personal communication, April 24, 2000), who confirmed that the flow chart is an actual representation of the current master scheduling and line-up process at EMP.
Customer orders are kept in the legacy system for the next 12 months

Customer orders for current and next two months are manually entered in Excel workbook

Customer orders are broken down in weekly buckets based on customer due date and % of painted engines

Customer orders are broken down in daily buckets for the next 20 days based on customer due date and % of painted engines

Is % of painted engines < 70% and customer due date met?

YES

Build date is assigned to each order for the next 20 days in daily buckets

NO

Check if the output is O.K.?

YES

A
Freeze the next day of schedule

Frozen schedule is manually sequenced based on small batches of paints

Generate build schedule for the final assembly line

**Figure 6.** Control group flow chart for the master scheduling and line-up process.

**Experimental Group**

A flow chart for the experimental group is illustrated in Figure 7. This flow chart was also reviewed by the key expert in the area of production planning and control at EMP (D. Eck, personal communication, April 24, 2000). Detailed discussion about the new master scheduling and line-up process is presented in the next section. Snapshots of each Excel worksheet are described with the various Excel functions that were used for the development of the scheduling and sequencing model in Excel.
Data set is received through automated e-mail message

Data set containing engine orders is imported in 20-day scheduling optimization

Layout of data is performed using various Excel functions including: format, lookup tables, and formulas

Data are sorted based on target build date in ascending order

Orders are compared with the previous day's frozen schedule

Was the order frozen the previous day?

NO

Eliminate the frozen order from the file

YES

B

C

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
NO

Check if the output is O.K.?

YES

Freeze the next day schedule

Import frozen schedule in the sequencing model

Sequencing of engines is performed based on constraint theory

Does the sequencing optimization minimize the constraint penalty points?

YES

Generate the build schedule for the final assembly line

Re-arrange the build dates

Non frozen orders are linked to the optimization tab

Build date is assigned to each order for the next 20 days based on constraints through optimization process

Figure 7. Experimental group flow chart for the master scheduling and line-up process.
Lack of time and capital resources limited the complete implementation of constraints management five focusing steps of: (a) identify the constraint, (b) exploit the constraint, (c) subordinate all other operations to the constraint, (d) elevate the constraint, and (e) avoid inertia. Three of the five focusing steps were used to develop the proposed scheduling and sequencing model at EMP; (a) identify the constraint, (b) exploit the constraint, and (c) subordinate all other operations to the constraint. Scheduling and sequencing methods used for the proposed model were based on drum-buffer-rope (DBR), which “is the core of the scheduling procedure under TOC” (Duclos & Spencer, 1995, p. 176). Figure 8 presents a generic version of the model used.

The paint operation was identified as the constraint at EMP, as indicated in step 1 of the focusing steps of constraints management. The paint operation dictates the launch schedule of engines at the final assembly line, thus fulfilling the definition of “drum” according to the APICS Dictionary: “the drum is the rate or pace of production set by the system’s constraint” (p. 25). According to the Schragenheim and Ronen (1990), “drum is the exploitation of the constraint of the system.” Using the drum to determine the pace of the system and its capacity accomplishes step 2 (exploit the constraint). A constraint buffer, which provides time to protect constraint from disruptions, was established after the custom trim operation. In the DBR method, the rope is a communication process from the constraint (paint operation) to the gating operation (final assembly line) that checks or limits material released into the system to support the constraint.

The flow of engines is depicted in Figure 9. After the engines leaves the final assembly line, a decision is made on space availability in test cells. If space is available, an engine is moved into a test cell; if not, the engine goes to temporary storage location.
After the engines are tested, they need to go through head torque operation. Once they pass this point, a decision is made on the routing of engines. Engines that are to be painted need to proceed first through custom trim, then paint and final trim areas. Non-paint engines go directly to final trim before they are warehoused. If both the custom trim and final trim queues are full, the head torque operation is shut down and the operator helps the test cell operators.

Figure 10 shows the time needed at each operation for the process of engines. A buffer of seven hours was created before the paint operation to protect the constraint from disruptions. The size of the constraint buffer was determined by managerial evaluation including operators in the paint operation and their supervisor opinions.

![Figure 8. The application of CM at EMP.](image)
Figure 9. Flow of engines at EMP.
Figure 10. Flow rate of engines at EMP.
Scheduling model. Two-part model was developed in Excel, one part for scheduling and the other part for sequencing engines in order to utilize CM methods. In the scheduling part of the model, engine orders are assigned a date to be built based on the following constraint criteria:

1. Customer due date
2. Available capacity in final assembly line
3. Available capacity in the test department
4. Available capacity in the customer trim area
5. Available capacity in the paint area
6. Available capacity in the final trim area

Each day the scheduling model generated a daily build schedule for engines for the next 20 days. The build schedule was frozen for the first day of production and was adjusted daily for each of the remaining 19 days. Customer due date is the only hard constraint (constraint that cannot be violated) in this model. Soft constraints can be violated, but there is a penalty for each violation. The constraints and penalty points for each constraint are discussed in detail later in this section.

Figure 11 illustrates the first sheet of the scheduling model titled “import new orders.” A new file is downloaded everyday by clicking on the icon titled “IMPORT FILE.” Each file is updated daily in a folder saved on the server by the systems department. A macro was recorded with Microsoft Visual Basic in Excel to perform the import function from the server to the 20-day scheduling file. Each row represents an
### Table: Import new orders

<table>
<thead>
<tr>
<th>CUSTOMER</th>
<th>ORDER #</th>
<th>PART #</th>
<th>SHIP DATE</th>
<th>QUANTITY SEQUENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATERLOO</td>
<td>19991105</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
<tr>
<td>WATERLOO</td>
<td>19991122</td>
<td>RG23878</td>
<td>32541</td>
<td></td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
order in this file. If a customer orders 10 engines for the same date, these 10 engines are represented in 10 continuous rows.

Data set received from legacy systems needs to be formatted before it can be utilized in a Windows-based application. Additional information is assembled using a function in Excel called Vlookup table. Numerous Excel formulas were used to clean the data and make it usable for the optimization. In the next sheet, “format orders,” data are being filtered and cleaned. These formulas are visible in various figures in forthcoming sections. Figure 12 illustrates a snapshot of the “format orders” sheet, and Figure 13 illustrates the same sheet with the formulas in each cell visible. In the next sheet, “sort orders,” shown in Figure 14, data are filtered again and sorted based on “target build date” criteria in ascending order. Customer orders that need to be built early on were moved to the top of the list. Figure 15 illustrates the same sheet with formulas visible in the cells.
<table>
<thead>
<tr>
<th>number</th>
<th>factory</th>
<th>customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-2</td>
<td>IF (import new orders $1$J24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L23&gt;0, import new orders $1C23**)</td>
</tr>
<tr>
<td>2-3</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-4</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-5</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-6</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-7</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-8</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-9</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-10</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-11</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-12</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-13</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-14</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-15</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-16</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-17</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-18</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-19</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-20</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-21</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-22</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-23</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-24</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
<tr>
<td>2-25</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
<td>IF (import new orders $1$L24&gt;0, import new orders $1C24**)</td>
</tr>
</tbody>
</table>

Figure 13. Format orders with formulas visible in the cells.
Figure 15. Sort orders with formulas visible in the cells.
Before the orders are linked to the "optimization" sheet, they are compared with the previous day's frozen line-up. This step was necessary to avoid orders being duplicated. If an order is already frozen the previous day, that order will not be linked to the "optimization" sheet and thus will not be used for optimization. Figure 16 presents a snapshot of a "comparison" sheet, and Figure 17 depicts the same sheet with formulas visible in each cell.

Figures 18–23 illustrate various sections of the optimization sheet, the next step in the scheduling model. Figures 18 and 19 display the section in which available capacity in standard minutes is calculated for the j-hook capacity (final assembly line), test (engine test cells), custom trim (painted engines are trimmed before paint operation), final trim (painted engines are trimmed again after paint), and paint operations. Figures 20 and 21 illustrate the required capacity in standard minutes for the same processes. A calculation for the difference in available and required capacity for each process is also performed here. Figures 22 and 23 present the optimization sheet displaying scheduled orders with regard to customer ship dates. If an order is scheduled late, the date field is highlighted in red, making it readily visible for the master scheduler to adjust the schedule.
Figure 16. Comparison.
Figure 17. Comparison with formulas visible in the cells.
Figure 18. Optimization tab, available capacity section.
Figure 19. Optimization tab, available capacity section, with formulas visible in the cells.
Figure 20. Optimization tab, required capacity section.
Figure 21. Optimization tab, required capacity section, with formulas visible in the cells.
**Figure 22.** Optimization tab, scheduled orders with ship date relative to each customer.
Figure 23. Optimization tab, scheduled orders with ship date relative to each customer, formulas visible in the cells.
After the optimization is performed using genetic algorithms, the schedule for the first day is frozen (Figure 24). These orders are linked to the next spreadsheet titled "frozen line-up" in the 20-day scheduling optimization model. Orders are compared with these frozen orders before they are included in the optimization to eliminate any duplication. These orders are also linked to the sequencing part of the model called sequencing model, which is discussed in detail in the next section. The last sheet in the model (Figure 25) titled "engine info," includes part number, engine model, lead time in days and split time in minutes. This information is used for the final assembly line (j-hook).
<table>
<thead>
<tr>
<th>CUSTOMER</th>
<th>PART #</th>
<th>MODEL</th>
<th>DUE DATE</th>
<th>UNIQUE #</th>
<th>PAINT</th>
<th>SPLIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATERLOO</td>
<td>RG27009</td>
<td>6081HRW05</td>
<td>11/05/99</td>
<td>RG2700911/05/991</td>
<td>PAINT</td>
<td>2</td>
</tr>
<tr>
<td>WATERLOO</td>
<td>RG27009</td>
<td>6081HRW05</td>
<td>11/05/99</td>
<td>RG2700911/05/992</td>
<td>PAINT</td>
<td>2</td>
</tr>
<tr>
<td>WATERLOO</td>
<td>RG27009</td>
<td>6081HRW05</td>
<td>11/05/99</td>
<td>RG2700911/05/993</td>
<td>PAINT</td>
<td>2</td>
</tr>
<tr>
<td>WATERLOO</td>
<td>RG23880</td>
<td>6105HRW01</td>
<td>11/05/99</td>
<td>RG2388011/05/991</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>WATERLOO</td>
<td>RG23880</td>
<td>6105HRW01</td>
<td>11/05/99</td>
<td>RG2388011/05/992</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>WATERLOO</td>
<td>RG23879</td>
<td>6125HRW02</td>
<td>11/05/99</td>
<td>RG2387911/05/992</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG24389</td>
<td>6081HH005</td>
<td>11/05/99</td>
<td>RG2438911/05/992</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG24389</td>
<td>6081HH005</td>
<td>11/05/99</td>
<td>RG2438911/05/993</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG26785</td>
<td>6081HH008</td>
<td>11/05/99</td>
<td>RG2678511/05/991</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG26785</td>
<td>6081HH008</td>
<td>11/05/99</td>
<td>RG2678511/05/992</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG26786</td>
<td>6081HH009</td>
<td>11/05/99</td>
<td>RG2678611/05/991</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG26787</td>
<td>6081HH100</td>
<td>11/05/99</td>
<td>RG2678711/05/991</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG28787</td>
<td>6081HH100</td>
<td>11/05/99</td>
<td>RG2878711/05/992</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG28787</td>
<td>6081HH100</td>
<td>11/05/99</td>
<td>RG2878711/05/993</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG28787</td>
<td>6081HH100</td>
<td>11/05/99</td>
<td>RG2878711/05/994</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG28787</td>
<td>6081HH100</td>
<td>11/05/99</td>
<td>RG2878711/05/995</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG28787</td>
<td>6081HH100</td>
<td>11/05/99</td>
<td>RG2878711/05/999</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG28787</td>
<td>6081HH100</td>
<td>11/05/99</td>
<td>RG2878711/05/999</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>RG28787</td>
<td>6081HH100</td>
<td>11/05/99</td>
<td>RG2878711/05/999</td>
<td>PAINT</td>
<td>3</td>
</tr>
<tr>
<td>WATERLOO</td>
<td>RG28787</td>
<td>6081HH100</td>
<td>11/05/99</td>
<td>RG2878711/05/999</td>
<td>PAINT</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 24. Frozen line-up tab.
<table>
<thead>
<tr>
<th>MODEL</th>
<th>Lead Time</th>
<th>Paint</th>
<th>SPLIT</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>RG23811</td>
<td>6081 HR02</td>
<td>2</td>
<td>NON</td>
<td>1</td>
</tr>
<tr>
<td>RG23812</td>
<td>6081 HR03</td>
<td>2</td>
<td>NON</td>
<td>1</td>
</tr>
<tr>
<td>RG23878</td>
<td>6125 HR01</td>
<td>3</td>
<td>PAINT</td>
<td>5</td>
</tr>
<tr>
<td>RG23879</td>
<td>6125 HR02</td>
<td>3</td>
<td>PAINT</td>
<td>6</td>
</tr>
<tr>
<td>RG23880</td>
<td>6105 HR01</td>
<td>3</td>
<td>PAINT</td>
<td>6</td>
</tr>
<tr>
<td>RG24703</td>
<td>6081 HR09</td>
<td>2</td>
<td>NON</td>
<td>1</td>
</tr>
<tr>
<td>RG24972</td>
<td>6081 HR10</td>
<td>2</td>
<td>NON</td>
<td>1</td>
</tr>
<tr>
<td>RG26999</td>
<td>6081 TR01</td>
<td>2</td>
<td>NON</td>
<td>2</td>
</tr>
<tr>
<td>RG27003</td>
<td>6081 TR02</td>
<td>2</td>
<td>NON</td>
<td>1</td>
</tr>
<tr>
<td>RG29286</td>
<td>6081 TR09</td>
<td>2</td>
<td>NON</td>
<td>2</td>
</tr>
<tr>
<td>RG29288</td>
<td>6081 TR10</td>
<td>2</td>
<td>NON</td>
<td>2</td>
</tr>
<tr>
<td>RG27004</td>
<td>6081 HR01</td>
<td>2</td>
<td>PAINT</td>
<td>1</td>
</tr>
<tr>
<td>RG27009</td>
<td>6081 HR05</td>
<td>2</td>
<td>NON</td>
<td>1</td>
</tr>
<tr>
<td>RG27019</td>
<td>6081 HR06</td>
<td>2</td>
<td>NON</td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure 25.** Engine info tab.
To summarize the 20-day scheduling model: after orders are assigned to the first production day, that day’s production schedule is frozen; no additions or deletions can be made to the schedule. Once the first day is frozen, it is linked to the sequencing model, which is discussed in the next section.

Sequencing model. In the sequencing part of the model, sequencing of engines is performed based on the following constraint criteria:

1. Total number of set-ups at the final assembly line (J-Hook)
2. Total number of split changes at the final assembly line (J-Hook)
3. Number of painted engines built per hour
4. Avoiding continuous build of painted engines
5. Grouping of similar types of engine models together

The build schedule for the next production day is frozen every day based on the scheduling constraints mentioned in the previous section. This schedule updates the worksheet titled “frozen line-up” in the scheduling model. The frozen line-up worksheet is linked to the sequencing model (Figures 26-30). Figure 26 shows the section where constraint points and penalty assigned to each constraint are calculated (cells H3:K9). Columns B through E are linked to the frozen line-up worksheet of the 20-day scheduling model. These same columns are also updated automatically every time the frozen line-up worksheet is updated in the scheduling model.

All the constraints in the sequencing model were soft constraints for which individual constraints can be violated. However, each violation had predetermined penalty points which the model applied accordingly. Cells J3:J8 in Figure 26 indicate the...
violations for all five constraints. As can be seen, there were 28 violations of the setup constraint, caused by 28 setup changes resulting from the sequencing of the line up.

Correspondingly, for the other four constraints, violations were as follows:
(a) 31 split changes, (b) 42 paint violations, (c) 9 consecutive paint violations, and (d) 57 group models violations. Figures 27 and 28 illustrate the same information that appears in Figure 26 but the formulas are visible in the cells. Figures 29–30 illustrate the computation of each constraint for each row with and without formulas visible in the cells.
Figure 26. Sequencing tab, calculation of constraint points.
**Figure 27.** Sequencing tab, calculation of constraint points, with formulas visible in the cells (a).
### Figure 28

Sequencing tab, calculation of constraint points, with formulas visible in the cells (b).
Figure 29. Sequencing tab, computation of constraints.
Figure 30. Sequencing tab, computation of constraints, with formulas visible in the cells.
Site Selection

The site selected for this research was an engine manufacturing facility of a midwestern manufacturer of agriculture equipment, which has been employing the latest technology throughout the years. MMAE allocates more than 2% of its gross sales for research and development, indicating the company's commitment to innovation and its desire to stay ahead of its competition.

MMAE completed its first MRP installation in 1979 and has implemented parts of JIT since 1981 (Williams, 1986). By 1986, the company had implemented MRP in all its plants worldwide. JIT was first implemented within MMAE at a facility that produces hay and forage equipment for agricultural use. Considerable improvements, including a 58% reduction in inventories, were reported after implementing parts of the JIT system.

The engine manufacturing plant of MMAE has long been perceived as the focus factory throughout the organization. It was the second plant within MMAE to achieve the ISO 9000 certification. This facility employs traditional (MRP) and contemporary (JIT) manufacturing systems, a condition that serves the purpose of the present research.

The design and development of EMP was initiated in 1973. This facility has 915,000 square feet, 340,000 of which is allocated to the assembly area. EMP began production of diesel engines in February, 1976. The number of engines produced in 1995 was 29,500 including marine, natural gas, and diesel. This volume is made up of 400 series (7.6 and 8.1 liter) and 500 series (10.1 liter) engines. The engines produced at this facility are shipped to internal customers (MMAE agricultural and industrial divisions) and to numerous original equipment manufacturers (OEM). The share of OEM
production has grown from 3% of volume in 1976 to 15% in 1995 and is expected to reach 50% of volume by the year 2005.

EMP provides purchased and manufactured service parts for the engines built at this facility. The service performance level is measured in the following two ways:

• Fill out of the factory to the Parts Distribution Center (PDC)
• Fill from PDC to dealers

The management goal is to fill 100% of all orders from the factory to PDC and 97% from PDC to dealers each month. EMP currently is filling orders from the factory to PDC at 93% and from PDC to dealers at 98%.

**Software Selection**

Intense reliance on the legacy computer systems has been one of the concerns of MMAE. EMP also relies heavily on legacy computer systems for production planning and control. Many MMAE facilities have begun using Microsoft Excel as a production-planning tool. This usage was a factor in selecting Excel for the research model.

In the new information-driven economy, selecting software to help achieve organizational goals has become more complex than ever before. The selection of Evolver as an optimization tool was based on its price and availability through MMAE. Evolver, an optimization add-on for Microsoft Excel, uses genetic algorithms to solve complex optimization problems in such areas as finance, distribution, scheduling, resource allocation, manufacturing, budgeting, and engineering. Virtually any type of problem that can be modeled in Excel can be solved by Evolver, including previously unsolvable problems. Evolver, which requires no knowledge of programming or genetic
algorithm theory, is available in three versions: standard, professional, and industrial. The professional and industrial versions have increased problem capacities and advanced features, including the Evolver Developer's Kit. As noted in the literature review, genetic algorithms are becoming prevalent as an optimization tool for scheduling problems. Many software vendors offer genetic algorithm-based optimization software, but Evolver by Palaside Inc. was one of the first in the market.

Data Collection

The master scheduler plans production (via Excel) for the fiscal year in monthly time-buckets. Production for each three-month period (current and following two months) is planned in weekly buckets. The master scheduler gives the production in weekly buckets in Excel workbook to the scheduler, who is responsible for the engine line-up for the next 20 days. The scheduler performs the line-up in daily buckets for the next 20 days in the HOST system.

Customer orders are kept in the legacy computer system called Common Worldwide Interfactory System (CWIS). These orders are auto-downloaded into the MRP master schedule. All customers have offset days within the master scheduling process. An offset is the number of production days between the launch and the ship on the assembly line. MRP generates the master schedule in monthly buckets after considering the customer requirement date and number of offset days. Monthly buckets are broken down in weekly buckets when the master scheduler runs a program in the HOST MRP.
The purpose of this research was to develop and evaluate a model that will generate an improved engine schedule and sequence based on CM when compared with the current method. The actual line-up schedule and sequence that were used to build engines for the 100 production days between summer of 1999 and spring of 2000 at EMP were used for the comparison. These data were used in the simulation for the current scheduling and sequencing method (control condition), as well as for the proposed scheduling and sequencing model for optimization (experimental condition). After the scheduling and sequencing optimizations were performed, the results of these optimizations were used in simulation.

In the proposed model, the master scheduler would perform the engine line-up in Excel using the optimization tool Evolver. This line-up would be auto-downloaded in the HOST system. The model is intended to provide EMP's management with the ability to perform what-if analysis in a timely manner.

**Statistical Analysis**

After the output from the simulation run for both methods, current and proposed, was obtained, statistical analysis was performed. Various statistical tools were used to perform the analysis. The five variables compared and analyzed were as follows:

1. Cycle time of engines for the final assembly line and four downstream processes
2. Queue size in front of four downstream processes after final assembly line
3. Utilization of work centers in the final assembly line and four downstream processes
4. Flow rate of engines through the final assembly line and four downstream processes

5. Total output of engines through final assembly line and four downstream processes

Expected improvements in the five variables of the proposed scheduling and sequencing model are as follows:

1. Reduction in cycle time of engines for the final assembly line and four downstream processes (smaller number is better)

2. Reduction in queue size in front of four downstream processes after final assembly line (smaller number is better)

3. Increase in the utilization percentage of work centers in the final assembly line and four downstream processes (larger number is better)

4. Even flow rate of engines through the final assembly line and four downstream processes

5. Increase in total output of engines through final assembly line and four downstream processes (larger number is better)

Some analysis was performed as part of the simulation output, such as determining minimum and maximum values and total output of engines, but the majority of the analysis was done after assembling the simulation output from both methods, current and proposed. A sample output from the model was used to determine that the data were normally distributed. The statistical tools used to analyze the data included the following: arithmetic averages, minimum and maximum values for each dependent variable, standard deviation, percentage of utilization of work centers, and t-tests.
Model Validation

According to a key expert in GPSS/H and PROOF simulation modeling at the corporate office of MMAE (G. Rehn, personal communication, [e-mail], December 22, 1999), simulations at MMAE have proved highly valid although the number of validations of simulations has been limited. Two formal validations in the 1980s and one informal in the early 1990s have been made. A validation of a simulation of one of MMEA’s plant that manufacture cotton pickers for its 2X conveyor system in the early 1980s found that in areas primarily equipment oriented, the correlation between the method in use and the simulated method was high (98%) but in the manpower-related instances, the confidence level was in the low 90s.

In 1988 a formal model validation was done for a simulation for the AGV assembly system in conjunction with the test acceptance. A statistician concluded that there was no significant difference between the simulation model and the behavior of the actual system. He recommended that the model be used to predict the effectiveness of future systems because it was quicker and easier to identify tendencies with the model.

In the validation performed in the early 1990s, a simulation model was compared with actual output in order to demonstrate the value of Optimax software. A month’s actual line-up at a seeding plant was used as an input for the simulated model. The actual output and the simulated output were so close that no statistical analysis was performed.

Thus in a limited number of cases, model have proved to be highly valid at MMAE. It should also be noted that the key expert at the corporate office of MMAE was consulted whenever questions arose regarding the design and testing of the model.
The proposed model is scheduled to be implemented at the EMP's final assembly line in the spring of 2000. Due to the time constraints for this research, model validation was conducted through computer simulation, using the software GPSS/H and PROOF, products of the Wolverine Software Corporation in Annandale, Virginia. GPSS/H is a simulation language, and PROOF is an animation software used within Excel file format. Excel serves as a user interface to the line-up model. It contains the launch sequence, shipping schedule, initial inventory, process cycle times, operating schedule by department (number of shifts in operation, etc.), number of operators/shift, and some equipment parameters such as number of load bars in the system. All these items are data-driven variables or inputs to the model. The parameters, once specified, define a specific simulation scenario to be tested through the model. An Excel macro that captures all the data defined in the Excel and creates various text files in a specific format understood by the simulation code was used.

GPSS/H, a simulation language, was used to write a model of the line-up alternatives. The simulation code accounts for all the resources, capacities, and process logic of the system. The model reads in all the data provided by the Excel interface and uses those conditions to execute all the "process" rules defined in the simulation code that represents the process flow of engines from the final assembly line to ship. At the end of the simulation run, the model generates output reports describing production volumes attained, operator utilization, equipment utilization, inventory levels, and total process cycle time, which is a function of the all the individual process cycle times and the dynamic delays associated with resource availability. The model also "writes" the graphic commands to a file to drive an animation depiction of the simulation test.
PROOF, the animation software, post-processes the graphic commands written by the simulation model. The result depicts the flow of the processes and illustrates the overall flow of the system. The animation first highlights any process issues and promotes understanding of the overall system. The related GPSS/H output then serves to quantify the performance. PROOF can also be used for some of the input data to the simulation, most often to show the configuration of the layout being tested. PROOF can translate DXF file formats from CAD programs and use them in the animation. Many of the layout capacities and conveyor speeds and times come from the layout of the system, once it has been translated into PROOF.

An output file in plain text format is created each time a simulation run is performed and the outcome is illustrated in the output file. A copy of the output is attached in Appendix A.

Summary

This research was designed to identify production planning and control (PP&C) constraints at EMP and to develop and validate scheduling and sequencing model based on these constraints. The site for the research was an engine manufacturing plant of a midwestern manufacturer of agriculture equipment. The plant employs both traditional and contemporary manufacturing systems.

The independent variable in the research design is the method of scheduling and sequencing, the experimental condition being the proposed model and the control condition, the current scheduling and sequencing method. Dependent variables are cycle time, queue time, utilization of work centers, flow of engines, and total output of engines.
The software selected for the research model was Excel, with Evolver as an optimization tool.

A two-part model, based on constraints management philosophy of production planning and control methods, was developed by the researcher in Excel, one part for scheduling and the other for sequencing. Using data from the 100 production days during the fall of 1999 and the spring of 2000, simulations for the current scheduling and sequencing method and for the proposed model were compared. Output from the simulations for the experimental and control conditions was statistically analyzed, using arithmetic averages, minimum and maximum, values for each dependent variable, standard deviation, percentage of utilization of work centers, and t-tests.
CHAPTER IV

SIMULATION RESULTS AND DISCUSSION

As stated earlier, the purpose of this research was to develop and evaluate a model that would generate an improved engine schedule and sequence based on constraint management (CM) in comparison to the currently used method. The actual lineup schedule and sequence that were used to build engines for the 100 production days between summer of 1999 and spring of 2000 at EMP were used for the comparison. Dates for the data were selected after review by the key expert in the area of production planning and control at EMP (D. Eck, personal communication, April 24, 2000). The actual dates for the data used in this study are listed in Table 3. These data were used in the simulation for the current scheduling and sequencing method (control condition), as well as for the proposed scheduling and sequencing model for optimization (experimental condition).

The simulation was developed by the key expert in GPSS/H and PROOF simulation modeling at the corporate office of MMAE. GPSS/H is a simulation language, and PROOF is an animation software used within Excel file format. Excel serves as a user interface to the lineup model. It contains the launch sequence, shipping schedule, initial inventory, process cycle times, operating schedule by department (number of shifts in operation, etc.), number of operators/shift, and some equipment parameters such as number of load bars in the system (see Figures 31 and 32). All these items are data-driven variables or inputs to the model. After specifying the parameters, each simulation run was conducted with a specific simulation number. All the parameters maintained the same values for the 200 simulation runs. The only values...
<table>
<thead>
<tr>
<th>Line-up date</th>
<th>Test no.</th>
<th>Line-up date</th>
<th>Test no.</th>
<th>Line-up date</th>
<th>Test no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/24/1999</td>
<td>4</td>
<td>9/20/1999</td>
<td>38</td>
<td>11/30/1999</td>
<td>71</td>
</tr>
<tr>
<td>6/30/1999</td>
<td>8</td>
<td>10/4/1999</td>
<td>42</td>
<td>12/6/1999</td>
<td>75</td>
</tr>
<tr>
<td>7/1/1999</td>
<td>9</td>
<td>10/5/1999</td>
<td>43</td>
<td>12/7/1999</td>
<td>76</td>
</tr>
<tr>
<td>7/2/1999</td>
<td>10</td>
<td>10/6/1999</td>
<td>44</td>
<td>12/8/1999</td>
<td>77</td>
</tr>
<tr>
<td>7/6/1999</td>
<td>11</td>
<td>10/7/1999</td>
<td>45</td>
<td>12/9/1999</td>
<td>78</td>
</tr>
<tr>
<td>7/7/1999</td>
<td>12</td>
<td>10/8/1999</td>
<td>46</td>
<td>12/10/1999</td>
<td>79</td>
</tr>
<tr>
<td>8/10/1999</td>
<td>14</td>
<td>10/12/1999</td>
<td>48</td>
<td>12/14/1999</td>
<td>81</td>
</tr>
<tr>
<td>8/11/1999</td>
<td>15</td>
<td>10/13/1999</td>
<td>49</td>
<td>12/15/1999</td>
<td>82</td>
</tr>
<tr>
<td>8/13/1999</td>
<td>16</td>
<td>10/14/1999</td>
<td>50</td>
<td>12/16/1999</td>
<td>83</td>
</tr>
<tr>
<td>8/16/1999</td>
<td>17</td>
<td>10/15/1999</td>
<td>51</td>
<td>12/17/1999</td>
<td>84</td>
</tr>
<tr>
<td>8/17/1999</td>
<td>18</td>
<td>11/1/1999</td>
<td>52</td>
<td>12/20/1999</td>
<td>85</td>
</tr>
<tr>
<td>8/18/1999</td>
<td>19</td>
<td>11/2/1999</td>
<td>53</td>
<td>12/21/1999</td>
<td>86</td>
</tr>
<tr>
<td>8/19/1999</td>
<td>20</td>
<td>11/3/1999</td>
<td>54</td>
<td>12/22/1999</td>
<td>87</td>
</tr>
<tr>
<td>8/31/1999</td>
<td>25</td>
<td>11/10/1999</td>
<td>59</td>
<td>1/12/2000</td>
<td>92</td>
</tr>
<tr>
<td>9/7/1999</td>
<td>29</td>
<td>11/16/1999</td>
<td>63</td>
<td>1/19/2000</td>
<td>96</td>
</tr>
</tbody>
</table>
Figure 31. Excel interface for the simulation run, top section.
Figure 32. Excel interface for the simulation run, bottom section.
that changed were the lineup sequences. An Excel macro captured all the data defined in the Excel interface and created various text files in a specific format understood by the simulation code.

GPSS/H was used to write a model of the lineup alternatives. The simulation code (see Appendix B) accounts for all the resources, capacities, and process logic of the system. The model reads in all the data provided by the Excel interface and uses those conditions to execute all the "process" rules defined in the simulation code that represents the process flow of engines from the final assembly line to ship. At the end of the simulation run, the model generates output reports describing production volumes attained, operator utilization, equipment utilization, inventory levels, and total process cycle time, which is a function of all the individual process cycle times and the dynamic delays associated with resource availability. The model also "writes" the graphic commands to a file to drive an animation depiction of the simulation test. (See Appendix C for a snapshot of animation depiction of simulation run.)

PROOF post-processes the graphic commands written by the simulation model. The result depicts the flow of the processes and illustrates the overall flow of the system. The animation first highlights any process issues and promotes understanding of the overall system. The related GPSS/H output then serves to quantify the performance. PROOF can also be used for some of the input data to the simulation, most often to show the configuration of the layout being tested. PROOF can translate DXF file formats from CAD programs and use them in the animation. Many of the layout capacities and conveyor speeds and times come from the layout of the system, once it has been translated into PROOF.
An output file in plain text format is created each time a simulation run is performed, and the outcome is illustrated in the output file. A copy of the output appears in Appendix A.

The research questions stated in chapter I were the bases for this experimental study. These questions are reiterated below for quick reference.

1. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the cycle time for the final assembly line and four downstream processes at an engine manufacturing plant (EMP) of a midwestern manufacturer of agricultural equipment (MMAE)?

2. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the queue size for the final assembly line and four downstream processes at EMP?

3. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the utilization of work centers in the final assembly line and four downstream processes at EMP?

4. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the flow rate of engines through the final assembly line and four downstream processes at EMP?

5. What is the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on the total output of engines through the final assembly line and four downstream processes at EMP?
Various statistical tools were used to analyze the output from the simulation run for both methods, current and proposed. The five variables compared and analyzed were as follows:

1. Cycle time of engines for the final assembly line and four downstream processes
2. Queue size in front of four downstream processes after final assembly line
3. Utilization of work centers in the final assembly line and four downstream processes
4. Flow rate of engines through the final assembly line and four downstream processes
5. Total output of engines through the final assembly line and four downstream processes

Expected improvements in the five variables of the proposed scheduling and sequencing model were as follows:

1. Reduction in cycle time of engines for the final assembly line and four downstream processes (smaller number is better)
2. Reduction in queue size in front of four downstream processes after final assembly line (smaller number is better)
3. Increase in the utilization percentage of work centers in the final assembly line and four downstream processes (larger number is better)
4. Even flow rate of engines through the final assembly line and four downstream processes
5. Increase in total output of engines through final assembly line and four downstream processes (larger number is better)

**Cycle Time**

The results of the simulations indicated very little reduction in average cycle time after 100 runs for the control condition and 100 simulation runs for the experimental condition (see Figure 33 for a comparison of each condition’s cycle time for the 100 simulation runs.) The average cycle time for the control condition was 9.04 hours with a standard deviation of 1.14 and average cycle time for the experimental condition was 8.97 hours with a standard deviation of 1.01. Results of t-test indicated the following values: t-value = 1.24, df = 99, and two-tailed significance = .219. Thus, the difference between the control condition and the experimental condition results was not statistically significant, with an alpha level of .05.

A smaller standard deviation value for the experimental condition indicates that there is less variation in cycle time. In the manufacturing environment, less variability is better. One reason for a less-than-expected reduction in cycle time could be the increased production of painted engines for the experimental condition, which requires additional processes. (See Figure 33, which shows a spike for Test 51, a day when all engines built were painted.) Cycle time was reduced for 48 out of 100 days for the experimental condition versus 39 days for the control condition; for 13 days, cycle times were identical for both conditions (see Table 4).
Figure 33. Cycle time final assembly through warehouse in hours. The spike for Test 51 is due to the fact that on that particular day, all of the engines built were painted.
Table 4

Comparison Data for Cycle Time

<table>
<thead>
<tr>
<th>Measures</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (minutes)</td>
<td>9.04</td>
<td>8.97</td>
</tr>
<tr>
<td>SD</td>
<td>1.14</td>
<td>1.01</td>
</tr>
<tr>
<td>No. of days of reduced cycle time</td>
<td>39.00</td>
<td>48.00</td>
</tr>
</tbody>
</table>

Queue Size

The results of the simulations indicated very little reduction in queue size after 100 runs for the control condition and 100 simulation runs for the experimental condition. (See Figure 34 for a comparison of the queue size of each condition for the 100 simulation runs.) The average queue size for the control condition was 110.27 engines with a standard deviation of 2.45, and the average queue size for the experimental condition was 110.12 engines with a standard deviation of 2.29. Results of t-test indicated the following values: t-value = 0.54, df = 99, and two-tailed significance = .588. Since the value of two-tailed significance was greater than .05, the difference between results for the control and the experimental conditions was not statistically significant with an alpha level of .05.
Figure 34. Queue size.
Again a slightly smaller standard deviation value for the experimental condition indicates less variability in the system. Performance in the control condition was better for 44 days and in the experimental condition on 53 days; for the remaining 3 of 100 days, both performed the same (see Table 5). Improvements in queue sizes were observed during the simulation runs for the experimental condition. For the control condition, several times there was "feast or famine" in the queues during daily runs, but data were collected only for average queue sizes. The experimental condition demonstrated uniform queue size throughout the daily simulation runs. A uniform queue size throughout the day is preferred over a queue of wide variability.

Table 5

Comparison Data for Queue Size

<table>
<thead>
<tr>
<th>Measures</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>110.27</td>
<td>110.12</td>
</tr>
<tr>
<td>SD</td>
<td>2.45</td>
<td>2.29</td>
</tr>
<tr>
<td>No. of days of reduced queue size</td>
<td>44.00</td>
<td>53.00</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Utilization of Work Centers

The results of the simulations indicated improvement in utilization of work centers after 100 runs for the control condition and 100 simulation runs for the experimental condition. (See Figure 35 for a comparison of the control condition and the experimental condition for utilization of work centers for the 100 simulation runs.) The average utilization for the control condition was 41.33% with a standard deviation of 4.22, and the average utilization for the experimental condition was 42.25% with a standard deviation of 3.95. Results of the t-test indicated the following values: t-value = 3.72, df = 99, and two-tailed significance = .000. The difference between results for the control and the experimental conditions was statistically significant, with an alpha level of .05.

The utilization of work centers of test cells, custom trim, paint, and final trim was recorded and measured. Since the final assembly line was a computer controlled line, utilization of work centers was not recorded. Various operators were assigned to more than one work center, but measurements were recorded for the utilization of centers not for the utilization of operators. Total utilization for the four downstream processes of the experimental condition was increased by 2.23%. Utilization of work centers in the four downstream processes for the control condition is presented in Table 6 and for the experimental condition in Table 7.

Performance in the control condition was better than that in the experimental condition on 35 days, and performance for the experimental condition was better on 64 days; for the remaining day, both performed the same (see Table 8).
Figure 35. Utilization of work centers in test cells, custom trim, final trim, and paint. As noted the spike for Test 51 is due to the fact that on that particular day, all of the engines built were painted.
Table 6
Utilization of Work Centers for the Control Condition

<table>
<thead>
<tr>
<th>Work centers</th>
<th>Average (%)</th>
<th>SD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test cells</td>
<td>50.23</td>
<td>3.04</td>
</tr>
<tr>
<td>Custom trim</td>
<td>33.43</td>
<td>8.04</td>
</tr>
<tr>
<td>Final trim</td>
<td>39.67</td>
<td>2.95</td>
</tr>
<tr>
<td><strong>Paint</strong></td>
<td><strong>42.00</strong></td>
<td><strong>8.42</strong></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>41.33</strong></td>
<td><strong>4.22</strong></td>
</tr>
</tbody>
</table>

Table 7
Utilization of Work Centers for the Experimental Condition

<table>
<thead>
<tr>
<th>Work centers</th>
<th>Average (%)</th>
<th>SD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test cells</td>
<td>50.58</td>
<td>2.55</td>
</tr>
<tr>
<td>Custom trim</td>
<td>34.44</td>
<td>7.75</td>
</tr>
<tr>
<td>Final trim</td>
<td>40.18</td>
<td>3.03</td>
</tr>
<tr>
<td><strong>Paint</strong></td>
<td><strong>43.80</strong></td>
<td><strong>7.75</strong></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>42.25</strong></td>
<td><strong>3.95</strong></td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Table 8

Comparison Data for Utilization of Work Centers

<table>
<thead>
<tr>
<th>Measures</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>41.33%</td>
<td>42.25%</td>
</tr>
<tr>
<td>SD</td>
<td>4.22</td>
<td>3.95</td>
</tr>
<tr>
<td>No. of days of increased total</td>
<td>35.00</td>
<td>64.00</td>
</tr>
<tr>
<td>utiliz.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Because paint was thought to be the constraint of the system, the results for paint utilization are discussed separately. (See Figure 36 for a comparison of the control condition and the experimental condition for utilization of work centers in paint.) Paint utilization increased for the experimental condition, as expected, but the increase was not statistically significant. The average utilization of work centers in paint for the control and the experimental conditions was 41.99% and 43.80%, respectively. Performance in the control condition was better than that in the experimental condition on 31 days, and performance for the experimental condition was better on 68 days; for the remaining day, both performed the same (see Table 9).
Figure 36. Utilization of work centers in paint. Results from Test 51 were atypical because all the engines built on that day were painted, a process requiring more time.
Table 9

Comparison Data for Paint Utilization

<table>
<thead>
<tr>
<th>Measures</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>41.99%</td>
<td>43.80%</td>
</tr>
<tr>
<td>SD</td>
<td>8.42</td>
<td>7.75</td>
</tr>
<tr>
<td>No. of days of increased paint utiliz.</td>
<td>31.00</td>
<td>68.00</td>
</tr>
</tbody>
</table>

Flow Rate of Engines

A better, more even flow of engines through the final assembly line (j-hook) and four downstream processes (test cells, custom trim, final trim, and paint) was the anticipated improvement for the experimental condition, but this was not achieved. Tables 10 and 11 present average and standard deviations of flow rates of engines in minutes for the control and the experimental conditions, respectively. Because paint was considered to be the constraint of the system, special attention was paid to this operation's flow rate. However, data gathered from both groups indicated that the custom trim operation is the constraint. For the control condition simulation run, it took 16.13 minutes to process an engine in custom trim versus 15.90 minutes in paint. For the experimental condition simulation run the data indicated similar results, 15.56 minutes for each engine in the custom trim operation versus 15.31 minutes in paint. Even though the difference in minutes between custom trim and paint was very minimal, it was surprising nonetheless to find out that another operation might become the bottleneck.
Table 10

**Flow Rate of Engines for the Control Condition (Minutes/Engine)**

<table>
<thead>
<tr>
<th>Processes</th>
<th>Average</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-hook</td>
<td>4.21</td>
<td>0.23</td>
</tr>
<tr>
<td>Test cells</td>
<td>11.26</td>
<td>0.66</td>
</tr>
<tr>
<td>Custom trim</td>
<td>16.13</td>
<td>3.45</td>
</tr>
<tr>
<td>Final trim</td>
<td>10.85</td>
<td>1.87</td>
</tr>
<tr>
<td><strong>Paint</strong></td>
<td><strong>15.90</strong></td>
<td><strong>3.73</strong></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>58.35</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 11

**Flow Rate of Engines for the Experimental Condition (Minutes/Engine)**

<table>
<thead>
<tr>
<th>Processes</th>
<th>Average</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-hook</td>
<td>4.18</td>
<td>0.10</td>
</tr>
<tr>
<td>Test cells</td>
<td>11.66</td>
<td>4.78</td>
</tr>
<tr>
<td>Custom trim</td>
<td>15.56</td>
<td>3.11</td>
</tr>
<tr>
<td>Final trim</td>
<td>10.47</td>
<td>0.93</td>
</tr>
<tr>
<td><strong>Paint</strong></td>
<td><strong>15.31</strong></td>
<td><strong>3.05</strong></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>57.18</strong></td>
<td></td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
The average standard deviation of flow rate of engines in minutes for the five processes for the control and experimental conditions was 2.60 and 2.59, respectively. The number of days performance in the control condition was better than that in the experimental condition were 49, and the number of days performance in the experimental condition was better was 50; for the remaining day, performance was the same for both conditions (see Table 12).

For each condition, custom trim and paint, both of which were more time consuming than other operations, were reduced in cycle times, thereby evening the flow. The experimental condition demonstrated a reduction of 3.50% for custom trim and 3.70% for the paint operation. The experimental condition also demonstrated a reduction of 2.00% in total flow minutes versus the control condition flow minutes, but the goal to have a better flow for the five processes was not achieved.

Table 12

Comparison Data for Even Flow

<table>
<thead>
<tr>
<th>Measure</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>2.60</td>
<td>2.59</td>
</tr>
<tr>
<td>SD</td>
<td>0.23</td>
<td>0.22</td>
</tr>
<tr>
<td>No. of days of better even flow</td>
<td>49.00</td>
<td>50.00</td>
</tr>
</tbody>
</table>
Total Output of Engines

Simulation results indicated an increase in the total number of engines processed in the system after 100 runs for the control condition and 100 simulation runs for the experimental condition (see Figure 37). The average number of engines processed each day in the final assembly line and four downstream processes was 467.27 for the control condition with a standard deviation of 49.43. The comparative figure for the experimental condition was 478.07 engines with a standard deviation of 41.92. The smaller standard deviation number for the experimental condition indicates less variability compared with the control condition. The number of days performance in the control condition was better than in the experimental condition was 37, and the number of days performance in the experimental condition was better was 62: for the remaining day, performance was the same for both conditions (see Table 13). Results of the t-test indicated the following values: $t$-value = 3.18, $df = 99$, and two-tailed significance = .002, with an alpha level of .05. Thus, the difference between the control condition and the experimental condition results was statistically significant. Once again, it should be noted that the data from Test 51, a day when all engines built were painted, a process requiring more time, were atypical.

On average the total number of engines processed in the system increased by 10.8 per day in the experimental condition. The experimental condition produced more engines on 62 out of 100 days, versus 37 days for the control condition. One-day total output was the same for both conditions. Averages with standard deviations for the final assembly line (j-hook) and the four downstream processes are presented in Tables 14 and 15 for the control and experimental conditions, respectively.
Figure 37. Total engine processed in the system. The spike for Test 51 represents the atypical situation of all engines built that day being painted.
Table 13

Comparison Data for Total Output

<table>
<thead>
<tr>
<th>Measures</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>467.27</td>
<td>478.07</td>
</tr>
<tr>
<td>SD</td>
<td>49.43</td>
<td>41.91</td>
</tr>
<tr>
<td>No. of days of increased total output</td>
<td>37.00</td>
<td>62.00</td>
</tr>
</tbody>
</table>

Because paint was thought to be the bottleneck of the system, special attention was paid to this operation. The average number of engines painted for the control condition was 71.88 with a standard deviation of 15.58, and the average number of engines painted for the experimental condition was 74.92 engines with a standard deviation of 13.99. Results of the t-test indicated the following values: t-value = 4.03, df = 99, and two-tailed significance = .000 with an alpha level of .05. Thus the difference between the results for the control and the experimental conditions was statistically significant.

Paint output was increased by 3.04 units or 4.23%. On average, more engines were painted in the experimental condition on 61 out of 100 days, versus 18 days for the control condition. On 21 days, output was the same for both groups. (See Figure 38 for a comparison of paint production in each condition for the 100 simulation runs.)
Table 14

Number of Engines Processed in the System (Control Condition)

<table>
<thead>
<tr>
<th>Processes</th>
<th>Average</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-hook</td>
<td>105.04</td>
<td>4.69</td>
</tr>
<tr>
<td>Test cells</td>
<td>110.83</td>
<td>6.32</td>
</tr>
<tr>
<td>Custom trim</td>
<td>72.58</td>
<td>15.54</td>
</tr>
<tr>
<td>Final trim</td>
<td>106.94</td>
<td>7.31</td>
</tr>
<tr>
<td>Paint</td>
<td>71.88</td>
<td>15.58</td>
</tr>
<tr>
<td>TOTAL</td>
<td>467.27</td>
<td>49.43</td>
</tr>
</tbody>
</table>

Table 15

Number of Engines Processed in the System (Experimental Condition)

<table>
<thead>
<tr>
<th>Processes</th>
<th>Average</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-hook</td>
<td>105.55</td>
<td>2.39</td>
</tr>
<tr>
<td>Test cells</td>
<td>114.41</td>
<td>5.31</td>
</tr>
<tr>
<td>Custom trim</td>
<td>74.86</td>
<td>15.02</td>
</tr>
<tr>
<td>Final trim</td>
<td>108.33</td>
<td>5.21</td>
</tr>
<tr>
<td>Paint</td>
<td>74.92</td>
<td>13.99</td>
</tr>
<tr>
<td>TOTAL</td>
<td>478.07</td>
<td>41.92</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Figure 38. Paint output for the control and the experimental conditions.
A smaller standard deviation for both total output and paint production indicated less variability in the system for the experimental condition. As mentioned earlier, a lesser amount of variability is better in the manufacturing environment. The relatively small standard deviation for total output and paint production indicates more consistent production was achieved for the experimental condition.
CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This research was an extension of a previous unpublished study, which investigated the PP&C methods being used at a midwestern manufacturing organization involved in the production of agricultural equipment. The current research study identified the constraints inherent in the production planning and control system and then developed and validated a master production scheduling and sequencing optimization model based on constraints management and utilizing genetic algorithms.

As noted earlier, production planning and control are among the most critical activities in manufacturing. The expected results of this research were to allow manufacturing organizations to maximize the effectiveness of PP&C methods, thereby improving their competitive position in the global economy. To that end, the goal of this research was to develop an optimization model based on constraints management and genetic algorithms to address the constraints in the PP&C methods being used at the factory under study. Published reports of the application of CM in a line assembly environment have been limited. However, according to the research literature, CM has been applied successfully in the job shop environment. In the current research, only three of the five steps of CM were applied. Although the results for the five variables were not statistically significant, results for the experimental condition were the same or better than those for the control condition. It is important to note that improvements are more difficult to achieve in a line assembly environment because there is much less flexibility than in a job shop environment.
The specific objectives of this research were as follows: (a) identify the system's constraints, (b) develop a scheduling and sequencing model to address the identified constraints, (c) develop and validate the proposed model by simulation, and (d) identify and document improvements attributed to the operational change resulting from the implementation of the optimization model.

The research examined the impact of the master production scheduling and sequencing model based on constraints management and utilizing genetic algorithms on five variables for the final assembly line and four downstream processes at an engine manufacturing plant (EMP) of a midwestern manufacturer of agricultural equipment (MMAE). The variables were cycle time, queue size, utilization of work centers, flow rate of engines, and total output of engines.

A two-part model based on constraints management philosophy of production planning and control methods was developed by the researcher in Excel, one part for scheduling and the other for sequencing. Using data from 100 production days during the fall of 1999 and the spring of 2000, simulations for the current scheduling and sequencing method (the control condition) and for the proposed method (the experimental condition) were compared. Output from the simulations for the experimental and control conditions was statistically analyzed.

**Conclusions**

In the interpretation of output from the simulation runs, it is important to note that daily simulation runs were discrete in nature. Lineup data for each simulation run were used exclusively for that simulation run only; there was no carryover capacity or other
resources from previous days to be used the next day. If the production of the constraint operation was reduced for some reason, makeup the next day would not be possible because new line-up data would initiate the next day's simulation run.

During the 200 simulations run, the cycle time of engines for the final assembly line and four downstream processes was reduced, but the reduction was not statistically significant. Queue size was also reduced, as expected, but once again, the reduction was not statistically significant. Total utilization of work centers was increased, as expected, and the increase was statistically significant. Improvement for the flow rate of engines was minimal. The total output of engines increased, and the increase was statistically significant.

Every effort was made to simulate the actual manufacturing environment of the EMP. But since simulation models are just abstractions of reality, they cannot completely mirror the real-world system under study (Law & Kelton, 1991). Results from the simulation outputs can provide insight as to how and why performance for the experimental condition and the control condition differed (Guide, 1992). However, the effectiveness of this model cannot be known conclusively until it is properly implemented at EMP in the fall of 2000.

The exact results of this research are only applicable for the EMP if the manufacturing environment replicated in the model still exists. Generalizations of the findings of this research should be made with caution.
**Recommendations**

The following recommendations for future research are provided in view of the findings of this study:

1. In this research, all simulation parameters (shipping schedule, initial inventory, process cycle times, operating schedule by department, number of shifts in operation, number of operators/shift, number of load bars in the system) were held constant for the control and the experimental conditions, except the line-up sequence. It is recommended that the values for the simulation parameters could be manipulated.

2. This research model was designed for the assembly operation, but a similar model could be developed for the manufacturing environment, particularly repetitive-type operations.

3. Data collection for the variables during the simulation runs was limited in scope. Only averages and minimum and maximum values were collected. Averages do not always paint a complete picture of the situation. For example the researcher observed during the simulation runs for queue size that the number of engines at 8:00 a.m. in front of one process for the control condition was zero and an hour later that number was 15. The average for two hours was 7.5. Queue sizes for the experimental condition simulation during the same time period were 8 and 7 for an average of 7.5. Because only averages were recorded, performance for both conditions appeared to be the same. But in reality, this would not be the case. The experimental condition’s results would be preferred because of the consistency of queue size. In the future, simulation data should include different measures, ones that more accurately reflect reality.
4. It is recommended that multiple models could be built, based on different production planning and control strategies (JIT, MRP, etc.), and the results could be compared and analyzed.
REFERENCES


Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.


APPENDIX A

Simulation Output (Control Condition)
SCHEDULING AND SEQUENCING MODEL SIMULATION
CONTROL CONDITION

TEST: NUMBER 1

INPUT CONDITIONS:

- AVG. LINE RATE-1ST: 130.0 ENGINES/SHIFT
- AVG. LINE RATE-2ND: 0.0 ENGINES/SHIFT
- AVG. LINE RATE-3RD: 0.0 ENGINES/SHIFT
- # LOAD BARS - MAIN: 160
- HEAVY REPAIR: 45.0 MINS.
- LIGHT REPAIR: 20.0 MINS. 0% REJECT RATE
- CELL DELAY: 5.0 MINS. 0% DELAY RATE
- # EFFECTIVE DOCKS: 3

RESULTS AFTER: 1 SIMULATION DAYS

ENGINE PRODUCTION SUMMARY:

<table>
<thead>
<tr>
<th></th>
<th>TOTAL</th>
<th>AVG./DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-HOOK PRODUCTION</td>
<td>105</td>
<td>105.0</td>
</tr>
<tr>
<td>TEST PRODUCTION</td>
<td>112</td>
<td>112.0</td>
</tr>
<tr>
<td>CUSTOM TRIM PRODUCTION</td>
<td>65</td>
<td>65.0</td>
</tr>
<tr>
<td>FINAL TRIM PRODUCTION</td>
<td>109</td>
<td>109.0</td>
</tr>
<tr>
<td>PAINT PRODUCTION</td>
<td>66</td>
<td>66.0</td>
</tr>
<tr>
<td>ENGINE SHIPPED</td>
<td>131</td>
<td>131.0</td>
</tr>
<tr>
<td>TRUCKS SHIPPED</td>
<td>10</td>
<td>10.0</td>
</tr>
</tbody>
</table>

ENGINE PROCESS SUMMARY:

<table>
<thead>
<tr>
<th></th>
<th>AVG.</th>
<th>MAX.</th>
<th>MIN.</th>
<th>CURRENT</th>
</tr>
</thead>
<tbody>
<tr>
<td># ENGINES IN PROCESS/ J-HOOK TO 572:</td>
<td>53.6</td>
<td>100</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td># ENGINES IN 572 (TRUCK GRIDS):</td>
<td>67.8</td>
<td>118</td>
<td>11</td>
<td>95</td>
</tr>
<tr>
<td># TRUCK GRIDS:</td>
<td>5.7</td>
<td>10</td>
<td>-----</td>
<td>7</td>
</tr>
<tr>
<td>TOTAL ENGINES AFTER J-HOOK:</td>
<td>121.4</td>
<td>173</td>
<td>83</td>
<td>123</td>
</tr>
<tr>
<td>TRUCK DOCK USAGE SUMMARY:</td>
<td>0.3</td>
<td>3</td>
<td>-----</td>
<td>0</td>
</tr>
<tr>
<td>PROCESS TIME IN DAYS/ J-HOOK TO 572:</td>
<td>0.4</td>
<td>1.1</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>WAREHOUSE TIME IN DAYS:</td>
<td>0.4</td>
<td>1.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>TRUCK LOAD TIME IN DAYS:</td>
<td>0.2</td>
<td>0.6</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>ENGINE FINISH SEQUENCE VARIATION:</td>
<td>0.4</td>
<td>52</td>
<td>-70</td>
<td></td>
</tr>
</tbody>
</table>

FLOW RATE BY DEPARTMENT:

<table>
<thead>
<tr>
<th>DEPARTMENT (MINS/ENGINE)</th>
<th>TOTAL PRODUCED</th>
<th># ENGINES/DAY</th>
<th>#SHIFT/DAY</th>
<th>DAYS/WEEK</th>
<th>EFFECTIVE MINS./DAY</th>
<th>CALCULATED FLOW RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>564</td>
<td>105</td>
<td>105.0</td>
<td>1</td>
<td>5</td>
<td>440</td>
<td>4.2</td>
</tr>
<tr>
<td>568</td>
<td>17</td>
<td>17.0</td>
<td>2</td>
<td>5</td>
<td>880</td>
<td>51.8</td>
</tr>
<tr>
<td>569</td>
<td>112</td>
<td>112.0</td>
<td>3</td>
<td>5</td>
<td>1245</td>
<td>11.1</td>
</tr>
<tr>
<td>570</td>
<td>65</td>
<td>65.0</td>
<td>2</td>
<td>5</td>
<td>1120</td>
<td>17.2</td>
</tr>
<tr>
<td>571</td>
<td>109</td>
<td>109.0</td>
<td>2</td>
<td>5</td>
<td>1120</td>
<td>10.3</td>
</tr>
<tr>
<td>572</td>
<td>131</td>
<td>131.0</td>
<td>1</td>
<td>5</td>
<td>440</td>
<td>3.4</td>
</tr>
</tbody>
</table>
### J-Hook Changeovers

<table>
<thead>
<tr>
<th># Changeovers</th>
<th>Total Avg./Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4.0</td>
</tr>
<tr>
<td>Changeover Time (Hours)</td>
<td>0.2</td>
</tr>
<tr>
<td>% Changeover</td>
<td>----</td>
</tr>
</tbody>
</table>

### Hourly Flow Meter Summary (Units/Hour)

<table>
<thead>
<tr>
<th>Area</th>
<th>Avg.</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-Hook</td>
<td>11.7</td>
<td>17.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Test</td>
<td>7.0</td>
<td>15.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Custom Trim</td>
<td>6.5</td>
<td>13.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Final Trim</td>
<td>6.8</td>
<td>12.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Paint</td>
<td>5.5</td>
<td>8.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

### Critical Queue Summary

<table>
<thead>
<tr>
<th>Area</th>
<th>Avg.</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty</td>
<td>83.0</td>
<td>90.0</td>
<td>56.0</td>
</tr>
<tr>
<td>Attic</td>
<td>1.3</td>
<td>11.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Test Loop</td>
<td>6.4</td>
<td>16.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Custom Trim</td>
<td>4.0</td>
<td>15.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Final Trim</td>
<td>10.3</td>
<td>12.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Paint</td>
<td>4.7</td>
<td>14.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Engine Production Detail:

#### Daily Engines Shipped:

<table>
<thead>
<tr>
<th>Engine</th>
<th>Production Days:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>6081HRW03</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>6125HRW01</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6125HRW02</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6105HRW01</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6081TRW01</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>6081TRW02</td>
<td>18</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>6081HRW01</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>6081HRW05</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081HRW06</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081HRW07</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>6081HRW08</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6125HRW04</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>6081HDW01</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081HDW05</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081HDW06</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6101AT012</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>6101AT010</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>6081HH006</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>6081TF001</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td>6081HF001</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>6081AF001</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
</tbody>
</table>

#### Total: 131

### Daily Truck Shipment by Customer:

#### Production Days:
### CUSTOMER 1 2 3 4 5 6 7 8 9 10 TOTAL

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATERLOO</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>DAVENPORT</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>HITACHI</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>HARVESTER</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>OEM</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

### TOTAL

| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |

### ENGINE PROCESS DETAIL:

#### PROCESS TIME BETWEEN J-HOOK & 572 (IN HOURS):

<table>
<thead>
<tr>
<th>ENGINE #</th>
<th>COMPLETE</th>
<th>AVG</th>
<th>MAX</th>
<th>MIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>6081HRW03</td>
<td>8</td>
<td>12.1</td>
<td>21.7</td>
<td>2.3</td>
</tr>
<tr>
<td>6081HRW01</td>
<td>4</td>
<td>8.6</td>
<td>10.5</td>
<td>6.9</td>
</tr>
<tr>
<td>6081HRW02</td>
<td>8</td>
<td>8.7</td>
<td>9.6</td>
<td>7.3</td>
</tr>
<tr>
<td>6105HRW01</td>
<td>2</td>
<td>3.7</td>
<td>4.4</td>
<td>3.1</td>
</tr>
<tr>
<td>6081TRW01</td>
<td>56</td>
<td>4.5</td>
<td>24.0</td>
<td>1.4</td>
</tr>
<tr>
<td>6081TRW02</td>
<td>46</td>
<td>7.0</td>
<td>22.9</td>
<td>2.0</td>
</tr>
<tr>
<td>6081HRW01</td>
<td>14</td>
<td>12.4</td>
<td>22.0</td>
<td>2.3</td>
</tr>
<tr>
<td>6081HRW05</td>
<td>4</td>
<td>7.6</td>
<td>10.8</td>
<td>4.5</td>
</tr>
<tr>
<td>6081HRW06</td>
<td>4</td>
<td>12.4</td>
<td>21.7</td>
<td>2.8</td>
</tr>
<tr>
<td>6081HRW07</td>
<td>6</td>
<td>12.8</td>
<td>22.2</td>
<td>2.8</td>
</tr>
<tr>
<td>6081HRW08</td>
<td>2</td>
<td>12.5</td>
<td>21.9</td>
<td>3.1</td>
</tr>
<tr>
<td>6125HRW04</td>
<td>8</td>
<td>9.6</td>
<td>10.5</td>
<td>8.6</td>
</tr>
<tr>
<td>6081HDW01</td>
<td>4</td>
<td>7.3</td>
<td>9.8</td>
<td>4.7</td>
</tr>
<tr>
<td>6125HDW05</td>
<td>4</td>
<td>7.9</td>
<td>11.4</td>
<td>4.9</td>
</tr>
<tr>
<td>6081HDW05</td>
<td>4</td>
<td>7.4</td>
<td>10.1</td>
<td>5.0</td>
</tr>
<tr>
<td>6125ADW70</td>
<td>2</td>
<td>10.3</td>
<td>10.9</td>
<td>9.8</td>
</tr>
<tr>
<td>6081AT012</td>
<td>6</td>
<td>11.9</td>
<td>12.2</td>
<td>11.6</td>
</tr>
<tr>
<td>6081AT010</td>
<td>24</td>
<td>11.3</td>
<td>13.7</td>
<td>9.0</td>
</tr>
<tr>
<td>6081HH006</td>
<td>8</td>
<td>7.8</td>
<td>10.8</td>
<td>4.3</td>
</tr>
<tr>
<td>6081TF001</td>
<td>44</td>
<td>10.4</td>
<td>15.3</td>
<td>6.2</td>
</tr>
<tr>
<td>6081HF001</td>
<td>24</td>
<td>13.2</td>
<td>26.1</td>
<td>5.2</td>
</tr>
<tr>
<td>6081AF001</td>
<td>14</td>
<td>9.8</td>
<td>23.4</td>
<td>5.1</td>
</tr>
</tbody>
</table>

### TOTAL:

| 292 | 8.9 | 26.1 | 1.4 |

### WAREHOUSE TIME (IN HOURS):

<table>
<thead>
<tr>
<th>ENGINE #</th>
<th>COMPLETE</th>
<th>AVG</th>
<th>MAX</th>
<th>MIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>6081HRW03</td>
<td>8</td>
<td>2.9</td>
<td>4.5</td>
<td>1.7</td>
</tr>
<tr>
<td>6125HRW01</td>
<td>2</td>
<td>17.6</td>
<td>18.1</td>
<td>17.1</td>
</tr>
<tr>
<td>6125HRW02</td>
<td>2</td>
<td>16.7</td>
<td>17.3</td>
<td>16.2</td>
</tr>
<tr>
<td>6105HRW01</td>
<td>1</td>
<td>19.9</td>
<td>19.9</td>
<td>19.9</td>
</tr>
<tr>
<td>6081TRW01</td>
<td>40</td>
<td>11.1</td>
<td>21.3</td>
<td>1.4</td>
</tr>
<tr>
<td>6081TRW02</td>
<td>36</td>
<td>7.2</td>
<td>18.6</td>
<td>1.1</td>
</tr>
<tr>
<td>6081HRW01</td>
<td>10</td>
<td>4.7</td>
<td>4.7</td>
<td>1.2</td>
</tr>
<tr>
<td>6081HRW05</td>
<td>4</td>
<td>6.1</td>
<td>11.0</td>
<td>1.3</td>
</tr>
<tr>
<td>6081HRW06</td>
<td>4</td>
<td>2.6</td>
<td>3.7</td>
<td>1.8</td>
</tr>
<tr>
<td>6081HRW07</td>
<td>6</td>
<td>2.1</td>
<td>3.6</td>
<td>1.1</td>
</tr>
<tr>
<td>6081HRW08</td>
<td>2</td>
<td>2.2</td>
<td>3.2</td>
<td>1.2</td>
</tr>
<tr>
<td>6125HRW04</td>
<td>4</td>
<td>15.2</td>
<td>15.9</td>
<td>14.5</td>
</tr>
<tr>
<td>6081HDW01</td>
<td>4</td>
<td>6.3</td>
<td>11.1</td>
<td>1.3</td>
</tr>
<tr>
<td>6081HDW05</td>
<td>4</td>
<td>6.0</td>
<td>11.1</td>
<td>1.3</td>
</tr>
<tr>
<td>6081HDW06</td>
<td>4</td>
<td>6.3</td>
<td>11.2</td>
<td>1.4</td>
</tr>
<tr>
<td>6101AT012</td>
<td>3</td>
<td>11.1</td>
<td>11.2</td>
<td>10.9</td>
</tr>
<tr>
<td>6101AT010</td>
<td>12</td>
<td>13.1</td>
<td>15.2</td>
<td>11.3</td>
</tr>
<tr>
<td>6081HH006</td>
<td>6</td>
<td>6.2</td>
<td>11.5</td>
<td>1.1</td>
</tr>
</tbody>
</table>
### Truck Grid Time (Awaiting Shipment) in Hours

<table>
<thead>
<tr>
<th>Customer</th>
<th># Complete</th>
<th>Avg.</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterloo</td>
<td>9</td>
<td>8.1</td>
<td>21.3</td>
<td>1.9</td>
</tr>
<tr>
<td>Davenport</td>
<td>4</td>
<td>6.4</td>
<td>11.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Hitachi</td>
<td>1</td>
<td>15.2</td>
<td>15.2</td>
<td>15.2</td>
</tr>
<tr>
<td>Harvester</td>
<td>2</td>
<td>6.5</td>
<td>11.5</td>
<td>1.5</td>
</tr>
<tr>
<td>OEM</td>
<td>1</td>
<td>23.0</td>
<td>23.0</td>
<td>23.0</td>
</tr>
</tbody>
</table>

**Total:** 197

### Truck Load Time in Hours

<table>
<thead>
<tr>
<th>Customer</th>
<th># Complete</th>
<th>Avg.</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterloo</td>
<td>9</td>
<td>3.6</td>
<td>14.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Davenport</td>
<td>4</td>
<td>5.8</td>
<td>11.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Dubuque</td>
<td>1</td>
<td>10.9</td>
<td>10.9</td>
<td>10.9</td>
</tr>
<tr>
<td>Harvester</td>
<td>2</td>
<td>5.7</td>
<td>10.3</td>
<td>1.1</td>
</tr>
<tr>
<td>OEM</td>
<td>1</td>
<td>10.9</td>
<td>10.9</td>
<td>10.9</td>
</tr>
</tbody>
</table>

**Total:** 17

### Finish Sequence Variance

<table>
<thead>
<tr>
<th>Engine</th>
<th># Complete</th>
<th>Avg.</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6081HRW03</td>
<td>8</td>
<td>1.6</td>
<td>15</td>
<td>-12</td>
</tr>
<tr>
<td>6125HRW01</td>
<td>4</td>
<td>-2.5</td>
<td>10</td>
<td>-17</td>
</tr>
<tr>
<td>6125HRW02</td>
<td>4</td>
<td>-2.7</td>
<td>7</td>
<td>-9</td>
</tr>
<tr>
<td>6105HRW01</td>
<td>2</td>
<td>37.5</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>6081TRW01</td>
<td>56</td>
<td>19.8</td>
<td>52</td>
<td>-50</td>
</tr>
<tr>
<td>6081TRW02</td>
<td>46</td>
<td>9.6</td>
<td>48</td>
<td>-30</td>
</tr>
<tr>
<td>6081HRW01</td>
<td>14</td>
<td>-3.3</td>
<td>14</td>
<td>-17</td>
</tr>
<tr>
<td>6081HRW05</td>
<td>4</td>
<td>6.0</td>
<td>23</td>
<td>-6</td>
</tr>
<tr>
<td>6081HRW06</td>
<td>4</td>
<td>1.0</td>
<td>15</td>
<td>-11</td>
</tr>
<tr>
<td>6081HRW07</td>
<td>6</td>
<td>0.2</td>
<td>15</td>
<td>-11</td>
</tr>
<tr>
<td>6081HRW08</td>
<td>2</td>
<td>3.0</td>
<td>14</td>
<td>-8</td>
</tr>
<tr>
<td>6125HRW04</td>
<td>8</td>
<td>-9.8</td>
<td>-5</td>
<td>-17</td>
</tr>
<tr>
<td>6081HDW01</td>
<td>4</td>
<td>1.3</td>
<td>16</td>
<td>-14</td>
</tr>
<tr>
<td>6081HDW05</td>
<td>4</td>
<td>-4.2</td>
<td>16</td>
<td>-16</td>
</tr>
<tr>
<td>6081HDW06</td>
<td>4</td>
<td>1.5</td>
<td>19</td>
<td>-13</td>
</tr>
<tr>
<td>6125ADW70</td>
<td>2</td>
<td>-13.5</td>
<td>-11</td>
<td>-16</td>
</tr>
<tr>
<td>6101AT012</td>
<td>6</td>
<td>-20.8</td>
<td>-18</td>
<td>-22</td>
</tr>
<tr>
<td>6101AT010</td>
<td>24</td>
<td>-17.0</td>
<td>-3</td>
<td>-39</td>
</tr>
<tr>
<td>6081HH006</td>
<td>8</td>
<td>3.1</td>
<td>17</td>
<td>-13</td>
</tr>
<tr>
<td>6081TF001</td>
<td>44</td>
<td>-19.4</td>
<td>15</td>
<td>-59</td>
</tr>
<tr>
<td>6081HF001</td>
<td>24</td>
<td>-4.2</td>
<td>32</td>
<td>-70</td>
</tr>
<tr>
<td>6081AF001</td>
<td>14</td>
<td>6.3</td>
<td>26</td>
<td>-10</td>
</tr>
</tbody>
</table>

**Total:** 292

### Technician Performance by Department

**Dept:** 568  
**Operating Days/Week:** 5

<table>
<thead>
<tr>
<th>Technician</th>
<th>Shift</th>
<th>Processed</th>
<th>Engine</th>
<th>% Ult.</th>
<th># Engines</th>
<th>Avg. Time/Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>TECHNICIAN</td>
<td>SHIFT</td>
<td># ENGINES</td>
<td>AVG. TIME/ENGINE</td>
<td>% ULT.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-------</td>
<td>-----------</td>
<td>------------------</td>
<td>--------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBTRIM</td>
<td>1</td>
<td>46</td>
<td>4.5</td>
<td>47.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBTRIM1</td>
<td>1</td>
<td>46</td>
<td>4.5</td>
<td>47.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LREPAIR</td>
<td>1</td>
<td>3</td>
<td>20.0</td>
<td>13.6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEAKTEST2</td>
<td>1</td>
<td>18</td>
<td>7.6</td>
<td>30.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBTRIM</td>
<td>2</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBTRIM1</td>
<td>2</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LREPAIR</td>
<td>2</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEAKTEST2</td>
<td>2</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DEPT: 569
OPERATING DAYS/WEEK: 5

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIFT</th>
<th># ENGINES</th>
<th>AVG. TIME/ENGINE</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEST5</td>
<td>1</td>
<td>50</td>
<td>7.9</td>
<td>95.0%</td>
</tr>
<tr>
<td>TEST7</td>
<td>1</td>
<td>46</td>
<td>7.8</td>
<td>86.1%</td>
</tr>
<tr>
<td>TEST9</td>
<td>1</td>
<td>43</td>
<td>7.6</td>
<td>79.0%</td>
</tr>
<tr>
<td>TEST11</td>
<td>1</td>
<td>38</td>
<td>7.8</td>
<td>71.4%</td>
</tr>
<tr>
<td>RETORQ1</td>
<td>1</td>
<td>74</td>
<td>3.6</td>
<td>64.1%</td>
</tr>
<tr>
<td>RETORQ2</td>
<td>1</td>
<td>7</td>
<td>3.4</td>
<td>4.0%</td>
</tr>
<tr>
<td>REPAIR1</td>
<td>1</td>
<td>8</td>
<td>37.1</td>
<td>71.5%</td>
</tr>
<tr>
<td>REPAIR2</td>
<td>1</td>
<td>6</td>
<td>27.6</td>
<td>40.0%</td>
</tr>
<tr>
<td>REPAIR3</td>
<td>1</td>
<td>5</td>
<td>26.0</td>
<td>31.3%</td>
</tr>
<tr>
<td>TEST5</td>
<td>2</td>
<td>23</td>
<td>7.3</td>
<td>40.4%</td>
</tr>
<tr>
<td>TEST7</td>
<td>2</td>
<td>19</td>
<td>7.4</td>
<td>33.9%</td>
</tr>
<tr>
<td>TEST9</td>
<td>2</td>
<td>20</td>
<td>7.1</td>
<td>34.2%</td>
</tr>
<tr>
<td>TEST11</td>
<td>2</td>
<td>21</td>
<td>7.3</td>
<td>36.8%</td>
</tr>
<tr>
<td>RETORQ1</td>
<td>2</td>
<td>29</td>
<td>2.9</td>
<td>20.1%</td>
</tr>
<tr>
<td>RETORQ2</td>
<td>2</td>
<td>6</td>
<td>24.7</td>
<td>35.7%</td>
</tr>
<tr>
<td>REPAIR1</td>
<td>2</td>
<td>4</td>
<td>31.0</td>
<td>29.9%</td>
</tr>
<tr>
<td>REPAIR2</td>
<td>2</td>
<td>3</td>
<td>30.0</td>
<td>21.7%</td>
</tr>
<tr>
<td>REPAIR3</td>
<td>2</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>TEST5</td>
<td>3</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>TEST7</td>
<td>3</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>TEST9</td>
<td>3</td>
<td>9</td>
<td>2.7</td>
<td>5.8%</td>
</tr>
<tr>
<td>RETORQ1</td>
<td>3</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

DEPT: 570
OPERATING DAYS/WEEK: 5

| CUSTOMT1   | 1     | 91        | 2.4              | 40.9%  |
| CUSTOMT2   | 1     | 106       | 2.3              | 46.6%  |
| CUSTOMT3   | 1     | 77        | 2.4              | 35.0%  |
| CUSTOMT4   | 1     | 98        | 2.3              | 42.5%  |
| CUSTOMT5   | 1     | 85        | 2.5              | 40.3%  |
| CUSTOMT1   | 2     | 45        | 2.8              | 21.2%  |
| CUSTOMT2   | 2     | 55        | 2.5              | 23.2%  |
| CUSTOMT3   | 2     | 49        | 2.1              | 17.4%  |
| CUSTOMT4   | 2     | 71        | 2.2              | 26.7%  |
| CUSTOMT5   | 2     | 62        | 2.2              | 23.1%  |

DEPT: 571
OPERATING DAYS/WEEK: 5

| FTRIM1     | 1     | 43        | 4.9              | 39.6%  |
| FTRIM2     | 1     | 95        | 1.7              | 30.1%  |
DEPT: 572  
OPERATING DAYS/WEEK: 5  

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIFT</th>
<th># TRUCKS PROCESSED</th>
<th>AVG. TIME/ TRUCK</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANALYST</td>
<td>1</td>
<td>11</td>
<td>4.5</td>
<td>11.4 %</td>
</tr>
<tr>
<td>SHIPPER1</td>
<td>1</td>
<td>11</td>
<td>10.9</td>
<td>27.3 %</td>
</tr>
<tr>
<td>SHIPPER2</td>
<td>1</td>
<td>11</td>
<td>11.8</td>
<td>29.5 %</td>
</tr>
<tr>
<td>TRUCKER1</td>
<td>1</td>
<td>4</td>
<td>18.7</td>
<td>17.0 %</td>
</tr>
<tr>
<td>TRUCKER2</td>
<td>1</td>
<td>5</td>
<td>20.0</td>
<td>22.7 %</td>
</tr>
<tr>
<td>TRUCKER3</td>
<td>1</td>
<td>4</td>
<td>18.7</td>
<td>17.0 %</td>
</tr>
<tr>
<td>CLERK</td>
<td>1</td>
<td>11</td>
<td>9.1</td>
<td>22.7 %</td>
</tr>
</tbody>
</table>

DEPT: 570  PAINT  
OPERATING DAYS/WEEK: 5  

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIFT</th>
<th># ENGINES PROCESSED</th>
<th>AVG. TIME/ ENGINE</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAINTR1</td>
<td>1</td>
<td>27</td>
<td>5.8</td>
<td>29.5 %</td>
</tr>
<tr>
<td>PAINTR2</td>
<td>1</td>
<td>26</td>
<td>6.7</td>
<td>33.1 %</td>
</tr>
<tr>
<td>PAINTR1</td>
<td>2</td>
<td>42</td>
<td>6.2</td>
<td>44.1 %</td>
</tr>
<tr>
<td>PAINTR2</td>
<td>2</td>
<td>46</td>
<td>7.2</td>
<td>55.8 %</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Simulation Output (Experimental Condition)
SCHEDULING AND SEQUENCING MODEL SIMULATION
EXPERIMENTAL CONDITION

TEST: NUMBER 1

INPUT CONDITIONS:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG. LINE RATE-1ST</td>
<td>130.0</td>
<td></td>
</tr>
<tr>
<td>AVG. LINE RATE-2ND</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>AVG. LINE RATE-3RD</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td># LOAD BARS - MAIN</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>HEAVY REPAIR</td>
<td>45.0 MINS.</td>
<td></td>
</tr>
<tr>
<td>LIGHT REPAIR</td>
<td>20.0 MINS.</td>
<td>@ 5% REJECT RATE</td>
</tr>
<tr>
<td>CELL DELAY</td>
<td>5.0 MINS.</td>
<td>@ 10% DELAY RATE</td>
</tr>
<tr>
<td># EFFECTIVE DOCKS</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

RESULTS AFTER: 1 SIMULATION DAYS

ENGINE PRODUCTION SUMMARY:

<table>
<thead>
<tr>
<th></th>
<th>TOTAL</th>
<th>AVG./DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-HOOK PRODUCTION</td>
<td>106</td>
<td>106.0</td>
</tr>
<tr>
<td>TEST PRODUCTION</td>
<td>111</td>
<td>111.0</td>
</tr>
<tr>
<td>CUSTOM TRIM PRODUCTION</td>
<td>68</td>
<td>68.0</td>
</tr>
<tr>
<td>FINAL TRIM PRODUCTION</td>
<td>111</td>
<td>111.0</td>
</tr>
<tr>
<td>PAINT PRODUCTION</td>
<td>72</td>
<td>72.0</td>
</tr>
<tr>
<td>ENGINE SHIPPED</td>
<td>139</td>
<td>139.0</td>
</tr>
<tr>
<td>TRUCKS SHIPPED</td>
<td>17</td>
<td>17.0</td>
</tr>
</tbody>
</table>

ENGINE PROCESS SUMMARY:

<table>
<thead>
<tr>
<th></th>
<th>AVG.</th>
<th>MAX.</th>
<th>MIN.</th>
<th>CURRENT</th>
</tr>
</thead>
<tbody>
<tr>
<td># ENGINES IN PROCESS/ J-HOOK TO 572:</td>
<td>49.6</td>
<td>87</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td># ENGINES IN 572 (TRUCK GRIDS):</td>
<td>54.3</td>
<td>99</td>
<td>11</td>
<td>68</td>
</tr>
<tr>
<td># TRUCK GRIDS:</td>
<td>8.7</td>
<td>15</td>
<td>-----</td>
<td>10</td>
</tr>
<tr>
<td>TOTAL ENGINES AFTER J-HOOK:</td>
<td>103.9</td>
<td>150</td>
<td>86</td>
<td>98</td>
</tr>
<tr>
<td>TRUCK DOCK USAGE SUMMARY:</td>
<td>0.5</td>
<td>3</td>
<td>-----</td>
<td>0</td>
</tr>
</tbody>
</table>

FLOW RATE BY DEPARTMENT:

<table>
<thead>
<tr>
<th>DEPARTMENT (MINS/ENGINE)</th>
<th>TOTAL PRODUCED</th>
<th># ENGINES /DAY</th>
<th>#SHIFT /DAY</th>
<th>DAYS/WEEK</th>
<th>EFFECTIVE MINS./DAY</th>
<th>CALCULATED FLOW RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>564</td>
<td>106</td>
<td>106.0</td>
<td>1</td>
<td>5</td>
<td>440</td>
<td>4.2</td>
</tr>
<tr>
<td>568</td>
<td>20</td>
<td>20.0</td>
<td>2</td>
<td>5</td>
<td>880</td>
<td>44.0</td>
</tr>
<tr>
<td>569</td>
<td>111</td>
<td>111.0</td>
<td>3</td>
<td>5</td>
<td>1245</td>
<td>11.2</td>
</tr>
<tr>
<td>570</td>
<td>68</td>
<td>68.0</td>
<td>2</td>
<td>5</td>
<td>1120</td>
<td>16.5</td>
</tr>
<tr>
<td>571</td>
<td>111</td>
<td>111.0</td>
<td>2</td>
<td>5</td>
<td>1120</td>
<td>10.1</td>
</tr>
<tr>
<td>572</td>
<td>139</td>
<td>139.0</td>
<td>1</td>
<td>5</td>
<td>440</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
### J-Hook Changeovers

<table>
<thead>
<tr>
<th></th>
<th>TOTAL</th>
<th>AVG./DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changeovers</td>
<td>7</td>
<td>7.0</td>
</tr>
<tr>
<td>Changeover Time (Hours)</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>% Changeover</td>
<td>6.6%</td>
<td></td>
</tr>
</tbody>
</table>

### Hourly Flow Meter Summary (Units/Hour)

<table>
<thead>
<tr>
<th>Area</th>
<th>Avg.</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-Hook</td>
<td>11.8</td>
<td>18.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Test</td>
<td>9.3</td>
<td>15.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Custom Trim</td>
<td>6.2</td>
<td>11.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Final Trim</td>
<td>7.9</td>
<td>13.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Paint</td>
<td>5.5</td>
<td>8.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

### Critical Queue Summary

<table>
<thead>
<tr>
<th>Area</th>
<th>Avg.</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty</td>
<td>85.5</td>
<td>90.0</td>
<td>67.0</td>
</tr>
<tr>
<td>Attic</td>
<td>0.8</td>
<td>9.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Test Loop</td>
<td>1.2</td>
<td>8.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Custom Trim</td>
<td>4.7</td>
<td>14.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Final Trim</td>
<td>9.9</td>
<td>12.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Paint</td>
<td>5.7</td>
<td>15.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Engine Production Detail:

#### Daily Engines Shipped:

<table>
<thead>
<tr>
<th>Engine</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>6081HRW03</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>6125HRW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6125HRW02</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6105HRW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6081TRW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>6081TRW02</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>6081HRW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>6081HRW05</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081HRW06</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>6081HRW07</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>6081HRW08</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6125HRW04</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>6081NDW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081NDW05</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081NDW06</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6101AT012</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>6101AT010</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>6101HH006</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>6081HDW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081HDW05</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081HDW06</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081AF001</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Total

<table>
<thead>
<tr>
<th>Engine</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>139</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>139</td>
</tr>
</tbody>
</table>

### Daily Truck Shipment by Customer:

#### Production Days:

<table>
<thead>
<tr>
<th>Engine</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>6081HRW03</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>6125HRW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6125HRW02</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6105HRW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6081TRW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>6081TRW02</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>6081HRW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>6081HRW05</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081HRW06</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>6081HRW07</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>6081HRW08</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6125HRW04</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>6081NDW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081NDW05</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081NDW06</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6101AT012</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>6101AT010</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>6101HH006</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>6081HDW01</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081HDW05</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081HDW06</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6081AF001</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Total

<table>
<thead>
<tr>
<th>Engine</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>139</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>139</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
<table>
<thead>
<tr>
<th>CUSTOMER</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATERLOO</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Davenport</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Hitachi</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Harvester</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>OEM</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17</td>
</tr>
</tbody>
</table>

ENGINE PROCESS DETAIL:

<table>
<thead>
<tr>
<th>PROCESS TIME BETWEEN J-HOOK &amp; 572 (IN HOURS):</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGINE # COMPLETE AVG. MAX. MIN.</td>
</tr>
<tr>
<td>6081HRW03 8 4.5 4.8 4.1</td>
</tr>
<tr>
<td>6125HRW01 3 9.1 9.6 8.8</td>
</tr>
<tr>
<td>6125HRW02 4 9.9 12.3 8.6</td>
</tr>
<tr>
<td>6105HRW01 2 5.4 7.0 3.9</td>
</tr>
<tr>
<td>6081TRW01 59 6.5 21.9 1.4</td>
</tr>
<tr>
<td>6081TRW02 18 12.2 21.6 2.3</td>
</tr>
<tr>
<td>6081HRW01 14 4.7 6.9 3.5</td>
</tr>
<tr>
<td>6081HRW05 4 9.6 10.3 8.9</td>
</tr>
<tr>
<td>6081HRW06 4 4.3 5.7 3.1</td>
</tr>
<tr>
<td>6081HRW07 6 4.4 5.9 3.3</td>
</tr>
<tr>
<td>6081HRW08 2 6.1 8.7 3.4</td>
</tr>
<tr>
<td>6125HRW04 8 9.3 10.0 8.7</td>
</tr>
<tr>
<td>6081HDW01 4 11.6 25.6 5.5</td>
</tr>
<tr>
<td>6081HDW05 4 7.9 9.1 5.4</td>
</tr>
<tr>
<td>6081HDW06 4 9.1 17.0 5.3</td>
</tr>
<tr>
<td>6125ADW70 2 9.5 10.0 9.1</td>
</tr>
<tr>
<td>6101AT072 24 8.6 12.6 6.9</td>
</tr>
<tr>
<td>6081TRW02 18 3.8 7.1 1.1</td>
</tr>
<tr>
<td>6081HRW01 14 10.8 20.4 1.4</td>
</tr>
<tr>
<td>6081HRW05 2 15.0 15.0 15.0</td>
</tr>
<tr>
<td>6081HRW06 4 10.7 20.1 1.5</td>
</tr>
<tr>
<td>6081HRW07 6 10.4 20.0 1.4</td>
</tr>
<tr>
<td>6081HRW08 2 8.6 16.0 1.3</td>
</tr>
<tr>
<td>6125HRW04 4 14.9 15.3 14.0</td>
</tr>
<tr>
<td>6081HDW01 4 5.3 17.2 1.2</td>
</tr>
<tr>
<td>6081HDW05 4 8.4 14.2 1.3</td>
</tr>
<tr>
<td>6081HDW06 4 7.0 14.3 3.9</td>
</tr>
<tr>
<td>6101AT012 3 15.0 15.7 13.9</td>
</tr>
<tr>
<td>6101AT010 12 17.1 19.0 12.6</td>
</tr>
<tr>
<td>6081HH006 6 7.1 12.7 1.1</td>
</tr>
<tr>
<td>TOTAL: 264 8.7 26.1 1.4</td>
</tr>
</tbody>
</table>

WAREHOUSE TIME (IN HOURS):

<table>
<thead>
<tr>
<th>ENGINE # COMPLETE AVG. MAX. MIN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6081HRW03 8 10.6 19.3 2.2</td>
</tr>
<tr>
<td>6125HRW01 2 15.5 15.6 15.4</td>
</tr>
<tr>
<td>6125HRW02 2 13.8 15.6 12.0</td>
</tr>
<tr>
<td>6105HRW01 1 16.9 16.9 16.9</td>
</tr>
<tr>
<td>6081TRW01 40 6.7 17.3 1.2</td>
</tr>
<tr>
<td>6081TRW02 18 3.8 7.1 1.1</td>
</tr>
<tr>
<td>6081HRW01 14 10.8 20.4 1.4</td>
</tr>
<tr>
<td>6081HRW05 2 15.0 15.0 15.0</td>
</tr>
<tr>
<td>6081HRW06 4 10.7 20.1 1.5</td>
</tr>
<tr>
<td>6081HRW07 6 10.4 20.0 1.4</td>
</tr>
<tr>
<td>6081HRW08 2 8.6 16.0 1.3</td>
</tr>
<tr>
<td>6125HRW04 4 14.9 15.3 14.0</td>
</tr>
<tr>
<td>6081HDW01 4 5.3 17.2 1.2</td>
</tr>
<tr>
<td>6081HDW05 4 8.4 14.2 1.3</td>
</tr>
<tr>
<td>6081HDW06 4 7.0 14.3 3.9</td>
</tr>
<tr>
<td>6101AT012 3 15.0 15.7 13.9</td>
</tr>
<tr>
<td>6101AT010 12 17.1 19.0 12.6</td>
</tr>
<tr>
<td>6081HH006 6 7.1 12.7 1.1</td>
</tr>
<tr>
<td>Engine Code</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>6081TRW01</td>
</tr>
<tr>
<td>6081HRW01</td>
</tr>
<tr>
<td>6081HRW02</td>
</tr>
<tr>
<td>6081HRW03</td>
</tr>
<tr>
<td>6081TRW02</td>
</tr>
<tr>
<td>6081HRW04</td>
</tr>
<tr>
<td>6081HRW05</td>
</tr>
<tr>
<td>6081HRW06</td>
</tr>
<tr>
<td>6081HRW07</td>
</tr>
<tr>
<td>6081HRW08</td>
</tr>
<tr>
<td>6081HRW09</td>
</tr>
<tr>
<td>6081HRW10</td>
</tr>
<tr>
<td>6081TRW01</td>
</tr>
<tr>
<td>6081TRW02</td>
</tr>
</tbody>
</table>

**TOTAL:** 264

**AVG. TIME/ENGINE:** 0.5

**% ULT.:** -54
<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIFT</th>
<th>PROCESSED</th>
<th>AVG. TIME/ENGINE</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBTRIM</td>
<td>1</td>
<td>48</td>
<td>4.4</td>
<td>48.4%</td>
</tr>
<tr>
<td>BBTRIM</td>
<td>1</td>
<td>47</td>
<td>4.5</td>
<td>47.9%</td>
</tr>
<tr>
<td>LREPAIR</td>
<td>1</td>
<td>3</td>
<td>2.0</td>
<td>13.6%</td>
</tr>
<tr>
<td>LEAKTEST2</td>
<td>1</td>
<td>16</td>
<td>7.5</td>
<td>27.3%</td>
</tr>
<tr>
<td>BBTRIM</td>
<td>2</td>
<td>10</td>
<td>3.2</td>
<td>7.2%</td>
</tr>
<tr>
<td>BBTRIM1</td>
<td>2</td>
<td>9</td>
<td>3.5</td>
<td>7.2%</td>
</tr>
<tr>
<td>LREPAIR</td>
<td>2</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>LEAKTEST2</td>
<td>2</td>
<td>6</td>
<td>6.7</td>
<td>9.1%</td>
</tr>
</tbody>
</table>

DEPT: 569  
OPERATING DAYS/WEEK: 5

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIFT</th>
<th>PROCESSED</th>
<th>AVG. TIME/ENGINE</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEST5</td>
<td>1</td>
<td>49</td>
<td>8.0</td>
<td>94.4%</td>
</tr>
<tr>
<td>TEST7</td>
<td>1</td>
<td>45</td>
<td>8.1</td>
<td>87.5%</td>
</tr>
<tr>
<td>TEST9</td>
<td>1</td>
<td>43</td>
<td>8.2</td>
<td>84.8%</td>
</tr>
<tr>
<td>TEST11</td>
<td>1</td>
<td>41</td>
<td>8.3</td>
<td>82.3%</td>
</tr>
<tr>
<td>RETORQ1</td>
<td>1</td>
<td>63</td>
<td>3.7</td>
<td>56.4%</td>
</tr>
<tr>
<td>RETORQ2</td>
<td>1</td>
<td>17</td>
<td>3.2</td>
<td>9.2%</td>
</tr>
<tr>
<td>REPAIR1</td>
<td>1</td>
<td>7</td>
<td>29.7</td>
<td>50.1%</td>
</tr>
<tr>
<td>REPAIR2</td>
<td>1</td>
<td>6</td>
<td>18.4</td>
<td>26.6%</td>
</tr>
<tr>
<td>REPAIR3</td>
<td>1</td>
<td>5</td>
<td>36.0</td>
<td>43.4%</td>
</tr>
<tr>
<td>TEST5</td>
<td>2</td>
<td>24</td>
<td>7.5</td>
<td>43.5%</td>
</tr>
<tr>
<td>TEST7</td>
<td>2</td>
<td>20</td>
<td>7.2</td>
<td>34.6%</td>
</tr>
<tr>
<td>TEST9</td>
<td>2</td>
<td>18</td>
<td>7.3</td>
<td>31.7%</td>
</tr>
<tr>
<td>TEST11</td>
<td>2</td>
<td>18</td>
<td>7.4</td>
<td>32.2%</td>
</tr>
<tr>
<td>RETORQ1</td>
<td>2</td>
<td>35</td>
<td>3.0</td>
<td>25.3%</td>
</tr>
<tr>
<td>RETORQ2</td>
<td>2</td>
<td>5</td>
<td>24.4</td>
<td>29.4%</td>
</tr>
<tr>
<td>REPAIR1</td>
<td>2</td>
<td>4</td>
<td>32.4</td>
<td>31.2%</td>
</tr>
<tr>
<td>REPAIR2</td>
<td>2</td>
<td>3</td>
<td>30.0</td>
<td>21.7%</td>
</tr>
<tr>
<td>TEST5</td>
<td>3</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>TEST7</td>
<td>3</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>TEST9</td>
<td>3</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>RETORQ1</td>
<td>3</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>REPAIR1</td>
<td>3</td>
<td>1</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

DEPT: 570  
OPERATING DAYS/WEEK: 5

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIFT</th>
<th>PROCESSED</th>
<th>AVG. TIME/ENGINE</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUSTOM1</td>
<td>1</td>
<td>87</td>
<td>2.9</td>
<td>47.0%</td>
</tr>
<tr>
<td>CUSTOM2</td>
<td>1</td>
<td>100</td>
<td>2.6</td>
<td>49.9%</td>
</tr>
<tr>
<td>CUSTOM3</td>
<td>1</td>
<td>86</td>
<td>2.1</td>
<td>34.1%</td>
</tr>
<tr>
<td>CUSTOM4</td>
<td>1</td>
<td>101</td>
<td>2.4</td>
<td>46.0%</td>
</tr>
<tr>
<td>CUSTOM5</td>
<td>1</td>
<td>90</td>
<td>2.3</td>
<td>38.4%</td>
</tr>
<tr>
<td>CUSTOM1</td>
<td>2</td>
<td>59</td>
<td>1.6</td>
<td>16.2%</td>
</tr>
<tr>
<td>CUSTOM2</td>
<td>2</td>
<td>65</td>
<td>2.3</td>
<td>24.8%</td>
</tr>
<tr>
<td>CUSTOM3</td>
<td>2</td>
<td>55</td>
<td>2.1</td>
<td>19.8%</td>
</tr>
<tr>
<td>CUSTOM4</td>
<td>2</td>
<td>60</td>
<td>2.3</td>
<td>23.0%</td>
</tr>
<tr>
<td>CUSTOM5</td>
<td>2</td>
<td>57</td>
<td>2.2</td>
<td>21.4%</td>
</tr>
</tbody>
</table>

DEPT: 571  
OPERATING DAYS/WEEK: 5

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIFT</th>
<th>PROCESSED</th>
<th>AVG. TIME/ENGINE</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTRIM1</td>
<td>1</td>
<td>55</td>
<td>5.1</td>
<td>52.9%</td>
</tr>
<tr>
<td>FTRIM2</td>
<td>1</td>
<td>128</td>
<td>1.6</td>
<td>38.0%</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIFT</th>
<th># TRUCKS PROCESSED</th>
<th>AVG. TIME/TRUCK</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANALYST</td>
<td>1</td>
<td>17</td>
<td>4.7</td>
<td>18.2%</td>
</tr>
<tr>
<td>SHIPPER1</td>
<td>1</td>
<td>16</td>
<td>12.2</td>
<td>44.3%</td>
</tr>
<tr>
<td>SHIPPER2</td>
<td>1</td>
<td>18</td>
<td>11.4</td>
<td>46.6%</td>
</tr>
<tr>
<td>TRUCKER1</td>
<td>1</td>
<td>6</td>
<td>20.8</td>
<td>28.4%</td>
</tr>
<tr>
<td>TRUCKER2</td>
<td>1</td>
<td>7</td>
<td>19.6</td>
<td>31.2%</td>
</tr>
<tr>
<td>TRUCKER3</td>
<td>1</td>
<td>7</td>
<td>21.4</td>
<td>34.1%</td>
</tr>
<tr>
<td>CLERK</td>
<td>1</td>
<td>18</td>
<td>9.4</td>
<td>38.6%</td>
</tr>
</tbody>
</table>

DEPT: 572
OPERATING DAYS/WEEK: 5

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIFT</th>
<th># ENGINES PROCESSED</th>
<th>AVG. TIME/ENGINE</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAINTR1</td>
<td>1</td>
<td>31</td>
<td>6.0</td>
<td>35.4%</td>
</tr>
<tr>
<td>PAINTR2</td>
<td>1</td>
<td>30</td>
<td>6.8</td>
<td>38.7%</td>
</tr>
<tr>
<td>PAINTR1</td>
<td>2</td>
<td>43</td>
<td>6.0</td>
<td>43.5%</td>
</tr>
<tr>
<td>PAINTR2</td>
<td>2</td>
<td>48</td>
<td>7.2</td>
<td>58.4%</td>
</tr>
</tbody>
</table>

DEPT: 570 PAINT
OPERATING DAYS/WEEK: 5
APPENDIX B

Simulation Code
SCHEDULING AND SEQUENCING MODEL SIMULATION CODE

DEVELOPED BY G. Rehn

* SIMULATE 3
  REALLOCATE COM, 900000
  REALLOCATE STO, 500, CHA, 500
  REALLOCATE FAC, 500, HSV, 300, GRP, 300
*
OCOLORC STARTMACRO
PUTTIME MACRO
  BPUTPIC FILE=ATF, (*A, *B)
Set C* Color *
ENDMACRO
*
  INTEGER &I, &J, &K, &L, &M, &N, &CDOW(18), &MAX, &CHOK, &PRVENG
  INTEGER &KEYCNT, &EFAM(20)
  REAL &R, &S, &T, &DAY, &CONVS, &HKCO, &PRORATE(6), &HOCKTOM
  REAL &MTBF(20), &DTIM(20), &DELAY(20)
  CHAR*12 &PTNO(100), &ENG, &CLR(8), &ECLR(100), &NULL
  VCHAR*12 &PRVCS, &PCLR(6), &NUM, &ITOCCHAR(50)
  *
  Define job attributes (fullword)

  ENGINE EQU 1, PF //ENGINE ID
  DELRT EQU 2, PF //DELIVERY DESTINATION
  REPAIR EQU 3, PF //ENGINE REPAIR INDICATOR
  RETEST EQU 4, PF //RETEST COUNT
  CVSEC EQU 5, PF //CURRENT CONTROL ZONE
  SEQNMQ EQU 6, PF //ASSEMBLY SEQUENCE #
  SUBR EQU 7, PF //SUBROUTINE PARAMETER
  PTR EQU 8, PF //POINTER PARAMETER
  CTR EQU 9, PF //COUNTER FARM.
  PLOC EQU 10, PF //PREVIOUS location
  CLOC EQU 11, PF //CURRENT LOCATION
  OPNUM EQU 12, PF //OPERATION #
  INDX EQU 13, PF //ULT. INDEX
  JNDX EQU 14, PF //ULT. INDEX
  SHFT EQU 15, PF //TECHNICIAN SHIFT
  PCT EQU 16, PF //WORKING PCT.
  RJCT EQU 17, PF //REJECT INDICATOR (0=NO; 1=YES)
  SSEQN EQU 18, PF //GRAND SEQUENCE #
  LCTR EQU 19, PF //LOOP COUNTER
  MOD EQU 20, PF //MODULE INDICATOR
  LOC1 EQU 21, PF //LOCATION 1
  LOC2 EQU 22, PF //LOCATION 2
  LOC3 EQU 23, PF //LOCATION 3
  LOC4 EQU 24, PF //LOCATION 4
  LOC5 EQU 25, PF //LOCATION 5
  LOC6 EQU 26, PF //LOCATION 6
  OPER1 EQU 27, PF //1ST OPERATOR IN SERIES
  OPERL EQU 28, PF //LAST OPERATOR IN SERIES
  TECHN EQU 29, PF //TECHNICIAN #
  PCODE EQU 30, PF //LOAD BAR PROCESS CODE
  NOOPR EQU 31, PF
  TSEQN EQU 32, PF //TRUCK SEQUENCE#
  *
  Define job attributes (floating)

  DELAY EQU 1, PL //HOT JOB DELAY
  ITIME EQU 2, PL //INDEX TIME
  WAIT EQU 3, PL //WAIT TIME
  CYCLE EQU 4, PL //CYCLE
  LAPTIM EQU 5, PL //TOTAL SYSTEM TIME
  CMPST EQU 6, PL //COMPLETION ESTIMATE

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
ACMBRK EQU 7, PL //ACCUMULATED BREAK

* File Variables.

* VCHAR* TESTID Test ID.
VCHAR*80 TESTDSCR Test description.
REAL PRODVO1(3) Daily production volume.
INTEGER RUNDAYS # of days to run.
INTEGER LBCTMN Load bar count in main conveyor.
INTEGER LBCTPNT Load bar count in paint.
REAL TRANSVEN Time in paint oven (min).

* REAL TRIM(100) Time: Trim
REAL TXFR(100) Time: Transfer
REAL TRM571(100) Time: Final Trim

* Data Declarations

INTEGER SHIFTNO, STAMPMIN, STAMP MID, STAMP MAX, DAYNO
VCHAR* 100 STRING1
INTEGER OFLDENGS
INTEGER FTRMENGs
INTEGER BMRG(40)

* CUSTOM TRIM STORAGES: 140-159

CTRMQ EQU 140.S.L //TRIM STATION
CTLINE EQU 141(9).S.L //TRIM LINE
STSTG0 EQU 155.S.L.C //STAGING ZONE
STRM1 EQU 156.S.L.C //DELIVERY PATH TO TRIMS
STRM1 EQU 157.S.L.C //TRANSFER SWITCH
TRMOUT EQU 158.S.L.C //EXIT TRIM AREA
TCTLINE EQU 151.S
TFTLINE EQU 152.S

* STORAGE S(140.A141-S148.A149.L7/S(STSTG0), 2
STORAGE S(STRM1),5/S(STRM1),1/S(TRMOUT),5
STORAGE S(TCTLINE),5/S(TFTLINE),9

* FINAL TRIM Storages: 160-179

FTRMQ EQU 160.S.L //FINAL TRIM QUEUE
FTLINE EQU 161(9).S.L //FINAL TRIM STATION
BBSWT EQU 179.L //BACKJONE SWITCH

* STORAGE S(FTRMQ), 12
STORAGE S(161-169), 1

* Paint Loop Storages: 180-199

SPNT1 EQU 180.S
SPNT2 EQU 181.S
SPNT3 EQU 182.S
SPNT4 EQU 183.S
SPNT5 EQU 184.S
SPNT6 EQU 185.S
SPNT7 EQU 186.S
SPNT8 EQU 187.S.C

* STORAGE S(SPNT1), 20/S(SPNT2), 3/S(SPNT3), 3/S(SPNT4), 1
STORAGE S(SPNT5), 1/S(SPNT6), 12/S(SPNT7), 5/S(SPNT8), 11

* 569 Repair Storages: 250-259

REPRQ EQU 250.S.L //REPAIR QUEUE
EREPR EQU 259.S //EXIT REPAIR
STORAGE $\text{S(REPRQ)}\, 4/S\text{EREPR},1$

* 568 Process Storages: 260-279

PRO568 EQU 260(9),F,S,C,L //568 REPAIR
TRM568 EQU 271(6),F,S,C,L //568 TRIM QUEUE
LEAKQ EQU 269,S,L,C //LEAK TEST QUEUE
LKTST2 EQU 270,S //LEAK TEST
STORAGE S260.5/S261-S263.8 //REPAIR SPURS
STORAGE S(LEAKQ),14/S270.1 //LEAK TEST QUEUE
STORAGE S272-S276.1/S271.3 //568 TRIM LINE

* Power & Free Storages: 280-290

SPL EQU 281,S,L
SPL2 EQU 282,S
SPQ EQU 284,S,F

* Gather statistics, traffic control Storages: 290+

DOCKS EQU 290,S
EWIPQ EQU 292,S //ENGINES FROM JHOOK TO 572
TOTALQ EQU 293,S //TOTAL ENGINES IN FACTORY

STORAGE S200.1

* TRANSIT COUNTS STORAGES 301-304

CSTRMCNT EQU 301,S //CUSTOM TRIM TRANSIT COUNT
FNTRMCNT EQU 302,S //FINAL TRIM TRANSIT COUNT
PAINTCNT EQU 303,S //PAINT TRANSIT COUNT
TSTLCOUNT EQU 304,S //TEST LOOP COUNT OUT
BACKMCNT EQU 305,S,L,C //BACKBONE TRANSIT LIMIT
BLUEFQ EQU 306,C,Q,L //BLUEBIRD FLOOR QUEUE

* Define Facilities and Storages.

BBCNV EQU 1(26),S,L
MORN EQU 27,L
COUNT EQU 28.XF,L //OLD RC COUNT
LJHOOK EQU 29.L //Logic flag: JHOOK transfer.
LTXFR EQU 30.L //Logic flag: TXFR transfer.
CELLS EQU 31(6),L,S
RTORKQ EQU 37,S,C,L //RETOURQUE QUEUE
RTORQ1 EQU 38.S,L //RETOURQUE STA 1
RTORQ2 EQU 39,S,L //RETOURQUE STA 2
RTORQ3 EQU 40.S,L //RETOURQUE QUEUE
BACKUP EQU 400,S
RECR1 EQU 401,S,L //569 RECIRC IN
RECR1 EQU 401,S,L,C //569 RECIRC
RECR1 EQU 403,S,L //569 EXIT
SPIN1 EQU 404,L //INDICATES RC 1 SEARCHING
RCAL1 EQU 404,C //CALL CHAIN FOR RC1
RECR2 EQU 405,S,L //570 RECIRC IN
RECR2 EQU 406,S,C,L //570 RECIRC MIDDLE
RECR2 EQU 407,S,L //570 EXIT
RECR2 EQU 408,S //TOTAL RECIRC LOOP
SPIN2 EQU 409,L //INDICATES RC 2 SEARCHING
RCAL2 EQU 410,C //RECIRC #2 CALL CHAIN
FAILR EQU 450,C //HOLD FAILURE COUNT
DLAYSW EQU 451(20),L //DELAY CONDITION SWITCHES

* STORAGE DEFINITION
STORAGE S1.6/S2.4/S3.14/S4.1/S5.2/S6.6/S7.13/S8.13
STORAGE S16.12/S17.27/S18.90/S19.8 //BACKBONE
STORAGE S31.2/S32.7/S33.2 //TEST CELL LOOP
STORAGE S34.1/S35.6/S36.4 //TEST CELL QUEUES
STORAGE S37.7/S38-S40.1 //RETORQUE STATIONS
STORAGE S(RECR10).1/S(RECR1).50/S(BACKUP).3

* Define Facilities.

EXIT1 EQU 77,F,XF EXIT PATH CLEAR
EXIT2 EQU 78,F,XF EXIT PATH CLEAR
ENTR1 EQU 79,F,XF EXIT PATH CLEAR
ENTR2 EQU 80,F,XF EXIT PATH CLEAR
CTEST1 EQU 81,F TEST CELL
CTEST2 EQU 82,F TEST CELL
CTEST3 EQU 83,F TEST CELL
CTEST4 EQU 84,F TEST CELL
CTEST5 EQU 85,F TEST CELL
CTEST6 EQU 86,F TEST CELL
CTEST7 EQU 87,F TEST CELL
CTEST8 EQU 88,F TEST CELL
CTEST9 EQU 89,F TEST CELL
CTEST10 EQU 90,F TEST CELL
CTEST11 EQU 91,F TEST CELL
CTEST12 EQU 92,F TEST CELL
CTEST13 EQU 93,F TEST CELL
CTEST14 EQU 94,F TEST CELL
CTEST15 EQU 95,F TEST CELL
CTEST16 EQU 96,F TEST CELL
CTEST17 EQU 97,F TEST CELL
CTEST18 EQU 98,F TEST CELL
CMCHT EQU 100(F).F ASSOC. CELL RUN TIME

CSPEED EQU 1,XL //CONV. SPEED

* PROCESS CODES & GROUPS

RCRQ1 SYN 1 //REIRCULATE
CLTEST SYN 2 //TEST CELL
RTOQ SYN 3 //RETORQUE
AUDIT SYN 4 //AUDIT
OFFLD SYN 5 //OFFLOAD
REPAIRS SYN 6 //REPAIRS
CSTRIM SYN 7 //CUSTOM TRIM
FNTRIM SYN 8 //FINAL TRIM
PNTSYS SYN 9 //PAINT SYSTEM
BBTRIM SYN 10 //BLUE BIRD TRIM

GRCRQ1 EQU 1,G
GCLTEST EQU 2,G
GRTORQ EQU 3,G
GAUDIT EQU 4,G
GOFFLD EQU 5,G
GREPAIRS EQU 6,G
GCSTRIM EQU 7,G
GFNTRIM EQU 8,G
GPNTSYS EQU 9,G
GBBTRIM EQU 10,G
GFNTRB EQU 11,G
GFNTRP EQU 12,G
GPNTSB EQU 13,G
TRKGRID EQU 51(50).XH,G //TRUCK GRID
TGRIDS EQU 1,Q //NUMBER OF OPEN GRIDS

* MATRIX DEFINITIONS

CSECT MATRIX ML,50.50 //CONV. SECTION TRAVEL DISTANCE
PROD MATRIX ML,100.20 //PRODUCTION MATRIX

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
File Definitions for files used in every scenario

INFILE FILEDEF 'INPUT.DAT' /*General Input Parameters
LAYOUT FILEDEF 'LAYOUT.DAT' /*Layout Definition
INVEN FILEDEF 'INV.DAT' /*Beginning Inventory
ALINEUP FILEDEF 'LINEUP.DAT' /*Assembly Lineup
DPT568 FILEDEF 'CYL568.DAT' /*568 Cycle Times
DPT569 FILEDEF 'CYL569.DAT' /*569 Cycle Times
DPT570 FILEDEF 'CYL570.DAT' /*570 Cycle Times
DPT572 FILEDEF 'CYL572.DAT' /*572 Cycle Times
DPT571 FILEDEF 'PAINT.DAT' /*571 Paint Parameters
TECHS FILEDEF 'TECHS.DAT' /*Technician Assignments
OPDAT FILEDEF 'OPERAT.DAT' /*Operation Schedules
CSTRM FILEDEF 'CTRIM.DAT' /*Custom Trim Line
FNTRM FILEDEF 'FTRIM.DAT' /*Final Trim Line
DWNTIM FILEDEF 'DWTIM.DAT' /*Downtime Scenarios
ATF FILEDEF 'TPS1.ATF' /*ttps Trace File
OUT FILEDEF 'OUTPUT.DAT' /*Output Report
TSUM FILEDEF 'TESTSUM.DAT'.APPEND /*ACCUMULATION TEST SUMMARY

* INITIALIZATION

INITIAL XLSCSPED 60.0  CONV. SPEED
INITIAL MLSCSEC(1,1) .34/MLSCSEC(2,1) .54
INITIAL MLSCSEC(3,1) .175/MLSCSEC(4,1) .14
INITIAL MLSCSEC(5,1) .32/MLSCSEC(6,1) .75
INITIAL MLSCSEC(7,1) .15/MLSCSEC(8,1) .159
INITIAL MLSCSEC(9,1) .39/MLSCSEC(10,1) .14
INITIAL MLSCSEC(11,1) .90/MLSCSEC(12,1) .30
INITIAL MLSCSEC(13,1) .26/MLSCSEC(14,1) .91
INITIAL MLSCSEC(15,1) .27/MLSCSEC(16,1) .26
INITIAL MLSCSEC(17,1) .35/MLSCSEC(18,1) .11.22
INITIAL MLSCSEC(19,1) .104
INITIAL MLSCSEC(31,1) .26/MLSCSEC(32,1) .84
INITIAL MLSCSEC(33,1) .18/MLSCSEC(34,1) .28
INITIAL MLSCSEC(39,1) .50

INITIAL MLSCSEC(1,11) .12/MLSCSEC(2,11) .33
INITIAL MLSCSEC(3,11) .35/MLSCSEC(4,11) .12
INITIAL MLSCSEC(9,11) .07
INITIAL MLSCSEC(11,11) .08/MLSCSEC(12,11) .07
INITIAL MLSCSEC(13,11) .12
INITIAL MLSCSEC(15,11) .15
INITIAL MLSCSEC(17,11) .14
INITIAL MLSCSEC(17,11) .14
INITIAL MLSCSEC(17,11) .14
INITIAL MLSCSEC(17,11) .14
INITIAL MLSCSEC(12,11) .13/MLSCSEC(13,11) .13
INITIAL MLSCSEC(38,11) .42/MLSCSEC(39,11) .21

INITIAL MLSCSEC(1,12) .33/MLSCSEC(2,12) .14
INITIAL MLSCSEC(3,12) .22/MLSCSEC(4,12) .12
INITIAL MLSCSEC(9,12) .08
INITIAL MLSCSEC(11,12) .08/MLSCSEC(12,12) .15
INITIAL MLSCSEC(13,12) .13
INITIAL MLSCSEC(15,12) .22
INITIAL MLSCSEC(17,12) .14
INITIAL MLSCSEC(17,12) .14
INITIAL MLSCSEC(12,12) .15/MLSCSEC(33,12) .14

INITIAL MLSCSEC(1,22) .16.92/MLSCSEC(1,23) .29.92
INITIAL MLSCSEC(1,24) .43/MLSCSEC(1,25) .54.66
INITIAL MLSCSEC(1,26) .41.55/MLSCSEC(1,27) .28.55
INITIAL MLSCSEC(1,28) .39.45/MLSCSEC(1,32) .38
INITIAL MLSCECT(1,13),58.82/MLSCECT(1,34),37.24
INITIAL MLSCECT(1,35),165.21/MLSCECT(1,36),82.92

LET &BBMRG(1)=1 //BB MERGE
LET &BBMRG(2)=1 //BB MERGE
LET &BBMRG(3)=1 //BB MERGE
LET &BBMRG(4)=1 //BB MERGE
LET &BBMRG(9)=1 //BB MERGE
LET &BBMRG(11)=1 //BB MERGE
LET &BBMRG(12)=1 //BB MERGE
LET &BBMRG(13)=1 //BB MERGE
LET &BBMRG(15)=1 //BB MERGE
LET &BBMRG(17)=1 //BB MERGE
LET &BBMRG(32)=1 //BB MERGE
LET &BBMRG(33)=1 //BB MERGE
LET &BBMRG(35)=1 //BB MERGE
LET &BBMRG(37)=1 //BB MERGE

BEGINNING OF BLOCK STATEMENTS

**CODE ADDITIONS FOR BLOCK AND JHOOK LINE**

REAL &APATH(100) //ASSEMBLY PATH DISTANCES
LET &APATH(1)=11.71
LET &APATH(2)=22.95
LET &APATH(3)=8
LET &APATH(4)=8
LET &APATH(5)=8
LET &APATH(6)=8
LET &APATH(7)=133.38
LET &APATH(8)=18.28
LET &APATH(9)=423.15
STORAGE S201.1/S202.2/S203-S206.1/S207.1/S208.2/S209.2/S210.1
REAL &FSP //FAST CONV. SPEED
LET &FSP=60.0
REAL &SSP //SLOW CONV. SPEED
REAL &OSP //OLD SPEED
INTEGER &INV572(100) //FINISHED ENGINE INVENTORY
INTEGER &INPROC //IN PROCESS ENGINES FROM JHOOK ON
INTEGER &EHPD(100) //ENGINES SHIPPED
INTEGER &TRKLD(1000) //TRUCK LOAD
VCHAR*12 &PARTNO1(100) //ENGINE PART NUMBER
VCHAR*30 &DUM1,&DUM2,&DUM3,&DUM4 //INPUT CHARACTERS
INTEGER &FINORD //FINISH ORDER OF ENGINES
INTEGER &SDAY
JHOOK SYN 200 //J-HOOK OFFSET
ASMLINE EQU 201(9),L,S //ASSEMBLY LINE ZONES
ASMPOS EQU 200(9),F //ASSEMBLY POSITION
ASMUL EQU 210,F,C,L //ASSEMBLY UNLOAD
JMLEAX EQU 211,F,C,L //LEAK TEST
JMLEX EQU 212(48),F //ASSEMBLY CHAIN PROCESS
PRO569 EQU 51(20),F //569 PROCESSES
PRO571 EQU 125(15),F //571 PROCESSES

* FACILITIES 300-400 RESERVED FOR TECHNICIANS
ASMLD EQU 200,C,L //ASSEMBLY LOAD
SSHRT EQU 201,C //SHIPPING SHORTAGES
INPROC EQU 202,C //PROCESS CHAIN
NOTCH EQU 203,C //NO TECHNICIANS
HOLD EQU 204,C //HOLD CHAIN
BBITQ EQU 205,C //BLUEBIRD INPUT TRUCKER
FLRPNTQ EQU 206,C //FLOOR PAINT QUEUE
BBOTQ EQU 207,C //BLUEBIRD OUTPUT TRUCKER
BBTRMQ EQU 208,C //BLUEBIRD TRIM QUEUE

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
ACELLS EQU 209,C //ACTIVE CELLS
FINV EQU 215,C //FINISHED INVENTORY
TRKHLD EQU 216,C //TRUCK HOLD
STPSHP EQU 217,C //STOP SHIPMENT
PDLAY EQU 218,C //DELAYED JOB
MATCH EQU 218,L //MATCH ONE DELY @ TIME
DINIT EQU 219,L //INDICATES INITILIZATION DONE
SWING EQU 219,C //HOLD POSITION FOR SWING TECHS
ONTRK EQU 220,C //ENGINES ON TRUCK
FLRSTQ EQU 221,C //FLOOR STAGE QUEUE
TCHNS SYN 300 //TECHNICIAN OFFSET

MATRIX MX. 205.5 //SHIPMENT SCHEDULE
MATRIX ML.10.5 //MISC. SYSTEM PERFORMANCE
MATRIX MH.100.21 //DAILY ENGINE SHIPMENTS
MATRIX MH.100.21 //DAILY TRUCK BY CUSTOMERS
MATRIX ML.100.5 //SHIPMENT DELAYS
MATRIX ML.100.5 //SEQUENCE VARIATION
MATRIX ML.100.5 //PROCESS TIME TO WH
MATRIX ML.100.5 //WAREHOUSE TIME
MATRIX ML.100.5 //GRID TIME BY CUSTOMER
MATRIX ML.100.5 //TRUCK LOAD TIME BY CUSTOMER

FVARIABLE PF(SEQN)-4FINORD //ENGINE SEQ VS. FINISH ORDER

//ACTIVE CELLS
//FINISHED INVENTORY
//TRUCK HOLD
//STOP SHIPMENT
//DELAYED JOB
//MATCH ONE DELY @ TIME
//INDICATES INITILIZATION DONE
//HOLD POSITION FOR SWING TECHS
//ENGINES ON TRUCK
//FLOOR STAGE QUEUE

REAL &ASMMAX //ASSEMBLY MAXIMUM
REAL &JHSPO(3) //JHOOK SPEED/SPLIT
REAL &PERF(10) //TECH. PERFORMANCE/MODULE
REAL &JHKUL //J-HOOK UNLOAD
REAL &LEAKRJ(2) //LEAK TEST REJECT% (1 & 2)
REAL &LEAKTST(2) //LEAK TEST TIMES (1 & 2)
REAL &LEAKRPR(2) //LEAK REPAIR TIMES (1 & 2)
REAL &HRPTXM //HEAVY REPAIR TIME
REAL &LRPTXM //LIGHT REPAIR TIME
REAL &CRPTXM //CELL REPAIR TIME
REAL &LRPRAJ //LIGHT REPAIR REJECT%
REAL &CRPRAJ //CELL REPAIR REJECT%
REAL &SIN568(100) //STARTING INVENTORY IN 568
REAL &SIN569(100) //STARTING INVENTORY IN 569
REAL &SIN570(100) //STARTING INVENTORY IN 570
REAL &SIN572(100) //STARTING INVENTORY IN 572
REAL &CTRM(100) //568 COMPRESSOR TRIM
REAL &BRTRM(100) //568 BLUEBIRD TRIM
REAL &RPASS(110) //REAL DATA INPUT VARIABLE
REAL &CPCTMN(100) //COMPRESSOR OPTIONS
REAL &CTST(100) //TEST CELL CYCLE TIME
REAL &HHK(100) //TEST CELL HOOK TIME
REAL &CNHK(100) //TEST CELL UNHOOK
REAL &RDOCK(100) //TIME FOR TEST CELL HOOK
REAL &RTOCK(100) //RETORQUE TIME/ENGINE
REAL &RTJ(1100) //1ST TEST REJECT%
REAL &RTJ2(1100) //2ND TEST REJECT%
REAL &BLOW(1100) //PAINT MIST & BLOW-OFF
REAL &MSTR(100) //MASK TIME
REAL &PCG(1100) //PRIME COAT CYCLE TIME
REAL &TCG(1000) //TOP COAT CYCLE TIME
REAL &REC'RS //REC'D TRUCKS/DAY
REAL &SHPTM(10) //572 CYCLE TIMES
REAL &FLASH //PAINT FLASH TIME/STOP
REAL &CST //PAINT COOL TIME/STOP
REAL &PNTFSP //PAINT DELIVERY SPEED
REAL &PNTSPP //PAINT PROCESS CHAIN SPEED
REAL &INSCT //INSPECT TIME
REAL &CYADJ //CYCLE TIME ADJUST
REAL &EFPROD(10) //ENGINE PRODUCTION BY MODULE
INTEGER &LBCJUK //J-HOOK CARRIERS
INTEGER &AMOD//ENGINE MODELS
INTEGER &TCRTE(100) //TEST CELL ROUTING(0=ANY)
INTEGER &DOCK // SHIPPING/REC DOCKS
INTEGER &PCMAX // MAX. # LOADS ON PROCESS CHAIN
INTEGER &SVAR // SAME STATION VARIABLE
INTEGER &TLAST // LAST TECHNICIAN
INTEGER &TCC // TECHNICIAN COUNT
INTEGER &TECHC(300) // TECHNICIAN COUNT
INTEGER &GBCNT(10) // GLOBAL COUNT
INTEGER &FCNT(10) // ENGINE COUNT (1ST TEST)
INTEGER &ENGCL1(100) // ENGINE COUNT (2ND TEST)
INTEGER &MD // MODULE POINTER
INTEGER &SF // SHIFT POINTER
INTEGER &LOC(6) // LOCATION PARAMETER
INTEGER &WDAYS(10) // WORK DAYS/WEEK/MODULE
INTEGER &WEK // # PRODUCTION DAYS/WEEK
INTEGER &GBCNT // GLOBAL COUNT
INTEGER &OPCNT(100) // ENGINE OPTION COUNT
INTEGER &ENG1(100) // ENGINE COUNT (1ST TEST)
INTEGER &ENG2(100) // ENGINE COUNT (2ND TEST)
INTEGER &ECLASSI(100) // ENGINE CLASS INTEGER BY ENGINE
INTEGER &BBLIM // BACKBONE LIMIT
INTEGER &ATHEAD // AT HEAD OF ATTIC
VCHAR*20 &CUSTMR(lOO) // CUSTOMER ID (UNIQUE)
VCHAR*20 &CUSTID(100) // CUSTOMER ID (UNIQUE)
VCHAR*20 &CPASS(lO) // CHARACTER VALUE PASS
VCHAR*10 &CPASS(10) // CHARACTER VALUE PASS
VCHAR*10 &SNAME(300) // STATION NAME
VCHAR*10 &SNAME(300) // STATION NAME
VCHAR*10 &ECLASSC(20) // ENGINE CLASS CHAR-DEFINITION

* VARIABLE DEFINITION *

CTRVL VARIABLE MLSCSECT(1,PFSCVSEC)/XLSCSPED CONV. TRAVEL
1 VARIABLE FS(81)*LS(41)
2 VARIABLE FS(82)*LS(42)
3 VARIABLE FS(83)*LS(43)
4 VARIABLE FS(84)*LS(44)
5 VARIABLE FS(85)*LS(45)
6 VARIABLE FS(86)*LS(46)
7 VARIABLE FS(87)*LS(47)
8 VARIABLE FS(88)*LS(48)
9 VARIABLE FS(89)*LS(49)
10 VARIABLE FS(90)*LS(50)
11 VARIABLE FS(91)*LS(51)
12 VARIABLE FS(92)*LS(52)
13 VARIABLE FS(93)*LS(53)
14 VARIABLE FS(94)*LS(54)
15 VARIABLE FS(95)*LS(55)
16 VARIABLE FS(96)*LS(56)
17 VARIABLE FS(97)*LS(57)
18 VARIABLE FS(98)*LS(58)

REPRODUCED WITH PERMISSION OF THE COPYRIGHT OWNER. FURTHER REPRODUCTION PROHIBITED WITHOUT PERMISSION.
BBMTR VARIABLE (LC260) AND (SNF(SPO)) AND (SE271)  //BLUEBIRD METER

NOBKUP VARIABLE (SFSBACKUP) AND (CHSBACKUP>0) AND (SNF$RECR1)  //BACKUP CONDITIONBBDOIOO

* FUNCTION DEFINITIONS

2 FUNCTION PF(CVSEC), D2  //CHAIN DIRECT
34, 21/36.22

3 FUNCTION PFSDELRT, D2 TEST CELL ENTRANCE PATH
6, 33/18, 32

4 FUNCTION PFSDELRT, D18 "IN" PATH TRAVEL TIME
1, .49/2, .42/3. .36/4, .28/5, .22/6, .14/7, .5/8, .42/9, .36/10, .29
11, .23/12, .15/13, .5/14, .42/15, .36/16, .29/17, .21/18, .19

5 FUNCTION PFSDELRT, D18 "OUT" PATH TRAVEL TIME
1, .06/2, .14/3, .2/4, .27/5, .32/6, .40/7, .07/8, .15/9, .2/10, .28
11, .33/12, .41/13, .07/14, .14/15, .20/16, .28/17, .33/18, .41

7 FUNCTION PFSDELRT, D2 TEST CELL ENTRANCE PATH
6, 80/18, 79

11 FUNCTION PFSDELRT, D2 TEST CELL EXIT PATH
6, 78/18, 77

12 FUNCTION PF(PCT), D18 //INITIAL %
1, 100/2, 50/3, 33/4, 25/5, 20/6, 16/7, 14/8, 12/9, 11/10, 10/11, 9/12, 8/13, 7/14, 6/15, 5/16, 4/17, 3/18, 2/19, 1/20
20, 5/25, 4/30, 3/35, 2/40, 1/45, 0/50, 0

13 FUNCTION PF(PCT), D39 //SECONDARY %
12, 0/13, 200/14, 0/15, 200/16, 400/17, 0/18, 199/19, 399/20, 0/21, 133/22, 199/23, 333
24, 499/25, 0/26, 125/27, 143/28, 200/29, 250/30, 132/31, 500/32, 1000/33, 0/34, 105
46, 667/35, 999/36, 1249/37, 2499/38, 0

TLOC1 FUNCTION PF(LCTRI), L6
PRO110/, PRO110/, PRO110/, PRO110/, PRO110/, PRO110/

TLOC2 FUNCTION PF(LCTRI), M6  //TECHNICIAN LOCATION #2
PFSLOC1/, PFSLOC2/, PFSLOC3/, PFSLOC4/, PFSLOC5/, PFSLOC6

PROCQ FUNCTION PF(LOC1), E6 //STORAGE DIRECT

LET &PCLR(1)='F3'
LET &PCLR(2)='F7'
LET &PCLR(3)='F4'
LET &PCLR(4)='F11'
LET &PCLR(5)='F2'
LET &PCLR(6)='F9'

LET &ITOCHAR(1)='1'
LET &ITOCHAR(2)='2'
LET &ITOCHAR(3)='3'
LET &ITOCHAR(4)='4'
LET &ITOCHAR(5)='5'
LET &ITOCHAR(6)='6'
LET &ITOCHAR(7)='7'
LET &ITOCHAR(8)='8'
LET &ITOCHAR(9)='9'
LET &ITOCHAR(10)='10'
LET &ITOCHAR(11)='11'
LET &ITOCHAR(12)='12'
LET &ITOCHAR(13)='13'
LET &ITOCHAR(14)='14'
LET &ITOCHAR(15)='15'
LET &ITOCHAR(16)='16'
LET &ITOCHAR(17)='17'
LET &ITOCHAR(18)='18'

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
LET &ITOCHAR(19) = '19'
LET &ITOCHAR(20) = '20'
LET &ITOCHAR(21) = '21'
LET &ITOCHAR(22) = '22'
LET &ITOCHAR(23) = '23'
LET &ITOCHAR(24) = '24'

* CONTROL STATEMENT PLUGS-INS
*
INSERT <CNTLDEF1.GPS>   //ANIMATION MACROS

* TECHNICIAN TO ELEMENT MATCH-UP MACRO
*
FNDTCH STARTMACRO #A
ALTERUCH E APOOL,1,LOCSPF,PFSCLOC,#A,PFSCLOC.PRO100   //PASS LOC
ALTERUCH E APOOL,1,CYCLESPL,PLSCYCLE,LOCSPF,PFSCLOC   //PASS CYCLE
BLET PL(CMPEST) =PLSCYCLE+AC1   //ESTIMATE COMPLETION
UNLINK APOOL.APOOL100,1,LOCSPF,PFSCLOC   //GET TECH
ENDMACRO
*

Simulation Timer Module
Written by G. Rehn
6/29/98
Version 01

** VARIABLES: **

| PF(CTR) = | Segment Pointer |
| PF(MOD) = | Module # |
| PF(OPER1) = | 1st Operator in Range |
| PF(OPERL) = | Last Operator in Range |
| PF(INDX) = | INDEX POINTER |
| PF(JNDX) = | INDEX POINTER |
| &MSHIFT(10) = | Initial Shift/Module |
| &MODID(10) = | Module Identifier |
| &OPXID(200) = | Operator ID Index |
| &OPR(200) = | Operator Color (Current)/Index |
| &SALOW = | Start-up Allowance |
| &CALOW = | Clean-up Allowance |
| &EFMIN(10) = | # Effective Mins/ Day |
| &OPHRS(10) = | # Total Hours |
| &OPSHIFT(10) = | # Operating Shifts/Module |
| &OPAS(100) = | Input Translation from Excel |
| &DFTOP(100) = | Default Operation Description |
| &ACNOOP(10) = | Accumulated Out of Operation Time |
| &CLKS = | Simulation Start Time |
| &AMPM(2) = | AM/PM START INDICATOR |
| &LS(MORN) = | MORNING SWITCH LC-MORNING/LS-AFTERNOON |
| &PE = | PAINT PURGE START |
| &PS = | PAINT START-UP TIME |
| Matrix HPS = | Hours/Shift (Halfword) |

** Row = Module **

| Cols 1-96= | Action in 15 Min. Increments |
| Row = Module |
| CoL = Shift (1,2,3) |

** TIMER CONTROL STATEMENTS **

INTEGER &OPXID(200)   //Operator ID Index
VCHAR*9 &OPR(200)   //Operator Color (Current)/Index
INTEGER &OPSHIFT(10)   //# Operating Shifts/Module
INTEGER &MSHIFT(10)   //Initial Shift / Module
REAL &EFMIN(10)   //# Effective Mins/ Day
REAL &OPHRS(10)   //# Total Hours
VCHAR*2 &OPAS(100)   //Input Translation from Excel
INTEGER &DFTOP(100)   //Default Operation
REAL &ACNOOP(10)   //Accumulated Out of Operation Time
VCHAR*2 &AMPM(2)  //AM/PM START INDICATOR
INTEGER &SD   //# Simulation Days
REAL &SALOW  //Start-up Allowance
REAL &CALOW  //Clean-up Allowance
REAL &CLKS   //Simulation Start Time
REAL &CLKPTH //Clock Path
INTEGER &PS,&PE  //PAINT PURGE/START TIME
.
TMDIR FUNCTION WH(HPS,PF(MOD),PF(CTR)),D5
-2,TMRBEGIN/-1,TMREND/3,TMRADV/15,TMRBRK/99,TMRSWG
.*
PCNVRT FUNCTION PF(CTR),E3  //POINTER CONVERT 0.96/96.PFSCTR/97.1
.*
ADJDL FVARIABLE MPSWAITSPL-(&ACNOOP(PFSMOD)-PLSACBRK)  //DELAY ADJUSTMENT
DISPT S-VARIABLE (&DFTOP(PFSCTR)<>0)AND(&DFTOP(PFSCTR)<>3)
TISFT S-VARIABLE (WH(HPS,2,PFSCTR)>0)AND(WH(HPS,2,PFSCTR)<=3)
LIMITS S-VARIABLE (PFSLOC=&SVAR)AND(PFSOPNUM>0)  //SAME STA. SEARCH
.*
HPS MATRIX WH,10,100  //HOURS PER SHIFT DESCRIPTION
TCH1 MATRIX WH,10,3  //FIRST TECHNICIAN/MODULE
TCH2 MATRIX WH,10,3  //LAST TECHNICIAN/MODULE
*-----------------------------------------------------------------------------------------------------
* VARIABLE DEFINITIONS (SEE EQU'S)
* BOOLEAN VARIABLE DEFINITIONS (ALL DIRECTLY ADDRESSED)
*
* FUNCTION DEFINITIONS (SEE EQU'S)
*
* MATRIX DEFINITIONS
*
LINEUP MATRIX MX,600.5  //ASSEMBLY LINEUP
PROD MATRIX ML,100.10  //PRODUCTION ATTAINED
*
* VARIABLE DEFINITIONS
*
ANYOP FVARIABLE PFSLOC1-PFSLOC2-PFSLOC3-PFSLOC4-PFSLOC5-PFSLOC6
TBULT FVARIABLE (ML(TECHBD,1,1J)/ML(TECHBD,1,7))*FRV(1)/10.0
*-----------------------------------------------------------------------------------------------------
* DATA READ LOGIC - INPUT SCENARIO
-----------------------------------------------------------------------------------------------------
GENERATE ...,1.,32FF,7PL  //SEED XACT
BGETLIST FILE=INFILFILE,ADUM  //TEST #4
BGETLIST FILE=INFILFIL,ADUM  //DESCRIPTION
BGETLIST FILE=INFILFIL,ADUM  //SKIP LINE
BGETLIST FILE=INFILF1,PRODVOL(1),&JHSPD(1)  //PRODUCTION-JHSPD/SHIFT
BGETLIST FILE=INFILF1,PRODVOL(2),&JHSPD(2)  //PRODUCTION-JHSPD/SHIFT
BGETLIST FILE=INFILF1,PRODVOL(3),&JHSPD(3)  //PRODUCTION-JHSPD/SHIFT
BLET &ASMAX=&JHSPD(1)  //ASSEMBLY MAXIMUM
TEST G &JHSPD(2),&ASMAX,=*2
BLET &ASMAX=&JHSPD(2)  //ASSEMBLY MAXIMUM
TEST G &JHSPD(3),&ASMAX,=*2
BLET &ASMAX=&JHSPD(3)  //ASSEMBLY MAXIMUM
BGETLIST FILE=INFILFIL,ADUM  //SIMULATION DAYS
BGETLIST FILE=INFILFIL,ADV  //EXIT TEST LIMIT
BGETLIST FILE=INFILFIL,CHOK  //SET STORAGE
BGETLIST FILE=INFILFIL,CHOK  //MAX. CUSTOM TRIM LIMIT
BGETLIST FILE=INFILFIL,CHOK  //SET STORAGE
BGETLIST FILE=INFILFIL,CHOK  //MAX. FINAL TRIM LIMIT
BGETLIST FILE=INFILFIL,CHOK  //MAX. PAINT LIMIT

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
INV110  BLET PF(INDX)=PF(INDX)+1  //BUMP
TEST NE &CUSTOMR(PFSINDX),'.',INV120  //NULL CUSTOMER
TEST NE &CUSTOMR(PFSINDX),&DUM,INV120
BLET PF(INDX)=PF(INDX)+1
BLET &CUSTOMR(PFSINDX)=&CUSTOMR(PFSINDX)
BLET &DUM=&CUSTOMR(PFSINDX)
INV120 LOOP LCTRSPF,INV110

*-----------------
* GET LINEUP
*-----------------

BOGETLIST FILE=ALINEUP,&DUM
BLET &I=0
SIP000 BLET &I= &I +1  //BUMP
BOGETLIST FILE=ALINEUP,END=SIP100,&DUM,MAX(SHIPS,&I,2),MAX(SHIPS,&I,4)
BLET &K=MAX(SHIPS,&I,4)-1000  //SAVE TRUCK
BLET MX(SHIPS,&I,4)=&K
BLET &TRKLD(&K)=&TRKLD(&K)+MX(SHIPS,&I,2)
BLET PF(LCTR)+&NOMDLS  //SEARCH FOR MODEL ID
SIP030 TEST NE &PARTNO(PFSLCTR),&DUM,STP040
LOOP LCTRSPF,SIP030  //KEEP LOOKING
BPUTPIC &DUM1, &I

ENGINE: * AT LINE ***** NOT FOUND CORRECT IN LINEUP OR BEGIN
TRANSFER .SIP000
SIP040 BLET MX(SHIPS,&I,1)=PF(LCTR)  //MODEL
BLET &DUM1=&CUSTOMR(PFSLCTR)
BLET PF(LCTR)=50
SIP050 TEST NE &DUM1, &CUSTOMR(PFSLCTR),SIP060
LOOP LCTRSPF,SIP050
SIP060 BLET MX(SHIPS,&I,3)=PF(LCTR)  //CUSTOMER ID
TRANSFER .SIP000  //GO AGAIN
SIP100 BCLOSE ALINEUP

*-----------------
* GET 568 CYCLE TIMES
*-----------------

BOGETLIST FILE=DPT568,&DUM  //SKIP LINE
BOGETLIST FILE=DPT568,&DUM  //SKIP LINE
BOGETLIST FILE=DPT568,&DUM  //SKIP LINE
CYL000 BOGETLIST FILE=DPT568,END=CYL090,&DUM,(&RPASS(&I),&I=1,3)
BLET PF(LCTR)+&NOMDLS
CYL010 TEST NE &DUM,&PARTNO(PFSLCTR),CYL020  //PART# SEARCH
LOOP LCTRSPF,CYL010  //CHECK MATCH
BPUTPIC FILE=OUT,&DUM
* * IN CYL568 NOT FOUND
TRANSFER .CYL000
CYL020 BLET &I=PF(LCTR)  //SAVE PART#
BLET &BTRM(&I)=&RPASS(1)  //BLUEBIRD TRIM TIME
BLET &CTRIM(&I)=&RPASS(2)  //COMPRESSOR TRIM TIME
BLET &COPTN(&I)=&RPASS(3)  //COMPRESSOR OPTION %
TRANSFER .CYL000
CYL090 BCLOSE DPT568

*-----------------
* GET 569 CYCLE TIMES
*-----------------

BOGETLIST FILE=DPT569,&DUM  //SKIP LINE
BOGETLIST FILE=DPT569,&DUM  //SKIP LINE
BOGETLIST FILE=DPT569,&DUM  //SKIP LINE
CYL100 BOGETLIST FILE=DPT569,END=CYL190,&DUM,(&RPASS(&I),&I=1,8)
BLET PF(LCTR)+&NOMDLS
CYL110 TEST NE &DUM,&PARTNO(PFSLCTR),CYL120  //PART# SEARCH
LOOP LCTRSPF,CYL110  //CHECK MATCH
BPUTPIC FILE=OUT,&DUM
* * IN CYL569 NOT FOUND
TRANSFER .CYL100
CYL120 BLET &I=PF(LCTR)  //SAVE PART#
BLET &CTEST(&I)=&RPASS(1)  //CELL TEST TIME
BLET &HOUR(&I)=&RPASS(2)  //HOOK-UP TIME
BLET &UNH(&I)=&RPASS(3)  //UNHOOK TIME
BLET &HLOOK(&I)=&RPASS(4)  //HOOK R-TIME
BLET &RTORK(&I)=&RPASS(5)  //RETORQUE TIME
BLET &TCRTE(&I)=&RPASS(6)  //CELL ROUTING

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
BLET &TRJT1(1) = &RPASS(7) // 1ST TIME REJECT %
BLET &TRJT2(1) = &RPASS(8) // 2ND TIME REJECT %
TRANSFER , CYL100
CYL190 BCLOSE DPT569

*---------------------------------
* GET 570/571 CYCLE TIMES
*---------------------------------

BGETLIST FILE = DPT570, &DUM // SKIP LINE
BGETLIST FILE = DPT570, &DUM // SKIP LINE
BGETLIST FILE = DPT570, &DUM // SKIP LINE
CYL200 BGETLIST FILE = DPT570, END = CYL290, &DUM, (&RPASS(1), &I = 1, 2), ...
   &J, (ARPASS(1), &I = 3, 7)
BLET PP(LCTR) = #MODLS
CYL210 TEST NE &DUM, &PARTNO(PSLCTR), CYL220 // PART# SEARCH
LOOP LCTRSPF, CYL210 // CHECK MATCH
* BPUTPIC FILE = OUT, &DUM
* * IN CYL570 NOT FOUND

TRANSFER , CYL200
CYL220 BLET &I = PP(LCTR) // SAVE PART#
BLET &TRIM(1) = &RPASS(1) // TRIM TIME
BLET &TXFR(1) = &RPASS(2) // PAINT TRANSFER TIME
BLET &BLOW(1) = &RPASS(3) // BLOW-OFF TIME
BLET &MASK(1) = &RPASS(4) // MASK TIME
BLET &PCOAT(1) = &RPASS(5) // PRIME COAT TIME
BLET &PCOAT(1) = &RPASS(6) // TOP COAT TIME
BLET &TRM571(1) = &RPASS(7) // FINAL TRIM TIME
TRANSFER , CYL200

*---------------------------------
* GET 572 CYCLE TIMES
*---------------------------------

BLET &I = 0
BGETLIST FILE = DPT572, &DOCK // # DOCKS
BSTORAGE SSDOKCS, &DOCK
BGETLIST FILE = DPT572, RECEIVING SHIPMENTS
BGETLIST FILE = DPT572, &DUM // SKIP LINE
CYL300 BGETLIST FILE = DPT572, END = CYL390, &DUM, (&RPASS(1), &DUM)
TEST E &DUM1, 'min load', CYL300 // PART# SEARCH
BLET &I = &I + 1
BLET &STECH(1) = &DUM // SHIPPING TECH
BLET &SHTIM(1) = &RPASS(1) // MASK/BLOW-OFF TIME
TRANSFER , CYL300
CYL390 BCLOSE DPT572

*---------------------------------
* GET PAINT PARAMETERS
*---------------------------------

BGETLIST FILE = DPT571, &LBCTPNT // PAINT LOAD BARS
BGETLIST FILE = DPT571, ATIMEOVEN // OVEN TIMER/LOAD BAR
BGETLIST FILE = DPT571, &FLASH // PAINT FLASH TIME/STOP
BGETLIST FILE = DPT571, &COOL // PAINT COOLDOWN/STOP
BGETLIST FILE = DPT571, &PNTFS // PAINT FAST SPEED
BGETLIST FILE = DPT571, &PNTSS // PAINT PROCESS SPEED
SPSPD MACRO PNT2, &PNTSS
BGETLIST FILE = DPT571, &PCMAX // PAINT PROCESS CHAIN MAX
BSTORAGE SSSPNT2, &PCMAX // WASHER LIMIT
BCLOSE DPT571

*---------------------------------
* READ IN DOWN TIME SCENARIOS
*---------------------------------

BGETLIST FILE = DWNTIM, &DUM
BLET PF(INDEX) = 0
DTS000 BLET PF(INDEX) = PF(INDEX) + 1 // BUMP INDEX VALUE
DTS000 BGETLIST FILE = DWNTIM, END = DTS010, &DUM, PF(JNDX), &DELAY1(PSLINDEX), ...
   &MTBF(PSLINDEX), &TIM(PSLINDEX), PF(LCTR)
SPLIT 1, DWT000
TRANSFER , DTS000
DTS100 BCLOSE DWTIM

* Simulation Timer Module

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
* Written by G. Rehn
* 6/29/98
* Version 01

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

Input Operation Data

CTM000 BLET &M=$CLKS/15-1
TEST E &M,97,*+2
BLET &M=#1
BGETLIST FILE=OPDAT.&DUM,(&OPAS(&J),&J=1,96)
BLET &I=#0

CTM010 BLET &J=I=1
TEST E &OPAS(&I),R,*-1
BLET &DFTOP(&I)=#15
TRANSFER .CTM020
TEST E &OPAS(&I),'F',*-1
BLET &DFTOP(&I)=#5
TRANSFER .CTM020
TEST E &OPAS(&I),'C',*-3
BLET &DFTOP(&I)=#10
TRANSFER .CTM020
TEST E &OPAS(&I),'A',*-3
BLET &DFTOP(&I)=#-2
TRANSFER .CTM020
BLET &DFTOP(&I)=CHARSTO1(&OPAS(&I))

CTM020 TEST E &I.96.CTM010

BLET PFCT(R)=&M
TEST E &DFTOP(&M),C,CTM04C

CTM030 BLET PFCT(R)=PFCT(R)-1
TRANSFER .CTM040

CTM040 BLET PFCT(R)=FN(PCNVRT)
TRANSFER .CTM040

CTM050 BLET PFCT(R)=PFCT(R)-1
TRANSFER .CTM040

CTM060 BLET &N=&DFTOP(PFCT(R))

CTM070 BLET &J=#0

CTM080 BLET &I=E=I=1
BGETLIST FILE=OPDAT.END=CTM190,.MODID(&I),(&OPAS(&I),&J=1,96),&EFMIN(&I),
&OPHRS(&I),&OPSFT(&I),&WDAYS(&I),&PERF(&I)
TEST G &EFMIN(&I),0.CTM180 //MODULE IN PLAY?
TEST E &WDAYS(&I),WEEK,**2 //WORK DAYS>WEEK?
BLET &WEEK=WDAYS(&I) //YES; NEW WEEK DEFINITION
BLET &OPAS(I),'O',CTM100 //DEFAULT?
BLET &J=0

CTM090 BLET &J=J=I=1
TRANSFER .CTM090

CTM100 BLET &J=#0

CTM110 BLET &J=#J=1
TEST E &OPAS(&J),B,**3
BLET MH(HPS,&I,&J)=15
TRANSFER .CTM120
TEST E &OPAS(&J),F,**3
BLET MH(HPS,&I,&J)=#5
TRANSFER .CTM120
TEST E &OPAS(&J),C,**3

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
BLET M(HPS, &I, &J) = 10
TRANSFER , CTM120
TEST E &OPAS(&J), 'A', *+3
BLET M(HPS, &I, &J) = -2
TRANSFER , CTM120
TEST E &OPAS(&J), 'E', *+3
BLET M(HPS, &I, &J) = -1
TRANSFER , CTM120
TEST E &OPAS(&J), 'S', *+3 // INDICATES SWING OPERATION
BLET M(HPS, &I, &J) = 99
TRANSFER , CTM120
BLET M(HPS, &I, &J) = CHARSTOI(&OPAS(&J))

CTM120 TEST E &I, &J, CTM110

* BLET PF(CTR) = &M
TEST E M(HPS, &I, PF(CTR)), -2, CTM140 // SHIFT START?
CTM130 BLET PF(CTR) = PF(CTR) + 1 // SEARCH FORWARD
BLET PF(CTR) = FN(PCNVRT) // POINTER CONVERT
TEST NE BV(TISPIT), 1, CTM160 // FOUND INITIAL?
TEST NE M(HPS, &I, PF(CTR)), -2, CTM130 // 0 START? LOOK BACKWARDS
TRANSFER , CTM140 // SEARCH FORWARD EVERYTHING ELSE

CTM140 BLET PF(CTR) = FN(PCNVRT) // POINTER CONVERT
TEST NE BV(TISPIT), 1, CTM160 // FOUND INITIAL SHIFT?
TEST NE M(HPS, &I, PF(CTR)), -2, CTM130 // 0 START? LOOK FORWARD
CTM150 BLET PF(CTR) = PF(CTR) - 1 // REDUCE
TRANSFER , CTM140
CTM160 BLET &MSHIFT(&I) = M(HPS, &I, PF(CTR)) // TAG INITIAL SHIFT

CTM180 TEST E &I, &I, CTM080 // FINISH READ
CTM190 BCLOSE OPDAT

* READ IN TECHNICIAN DATA

BLET PF(PLOC) = 0 // ZERO OUT FOR SWING ID
GETLIST FILE=TECHS, &DUM
TIN000 BGETLIST FILE=TECHS, END=DIN000, ERR=DIN000, PF(TECHN), &TCHNM(PF$TECHN), _
&DUM, &DUM1, PF(SHFT), (&CPASS(&J), &J = 1, 6)
TEST NE &TCHNM(PF$TECHN), '0', DIN000
TEST E &DUM1, 'Y', DIN000 // TECH IN PLAY?
BLET PF(MOD) = 10 // MOD SEARCH
TIN010 BLET &DUM, &MODID(PF$MOD), TIN010 // MODULE MATCH
LOOP MODSPF, TIN010 // KEEP LOOKING
TRANSFER , DIN000
TIN020 BLET PF(LCTR) = 6
TIN025 TEST NE &CPASS(PF$SCTR), '0', TIN060
BLET PF(INDX) = 0
TIN030 TEST NE &CPASS(PF$SCTR), &SNAME(PF$INDX), TIN040
TRANSFER , TIN030
TIN040 BLET PF(PF$SCTR+20) = PF(INDX)
TIN060 LOOP LCTRS$PF, TIN025
TIN070 BLET &K = V(ANYOP) // SUM OF ALL OPERATIONS
TEST G &K >= TIN000 // IF ZERO, NO TECH
BLET &LAST = PF$TECHN
BLET &TCC = &TCC - 1 // #TECHNICIAN
BLET MX(TCHASN, PF$TECHN, 1) = PF(MOD) // SAVE ASSIGNMENTS
BLET MX(TCHASN, PF$TECHN, 2) = PF(SHFT) // SAVE ASSIGNMENTS
BLET MX(TCHASN, PF$TECHN, 3) = PF(LC01) // SAVE ASSIGNMENTS
BLET MX(TCHASN, PF$TECHN, 4) = PF(LC02) // SAVE ASSIGNMENTS
BLET MX(TCHASN, PF$TECHN, 5) = PF(LC03) // SAVE ASSIGNMENTS
BLET MX(TCHASN, PF$TECHN, 6) = PF(LC04) // SAVE ASSIGNMENTS
BLET MX(TCHASN, PF$TECHN, 7) = PF(LC05) // SAVE ASSIGNMENTS
BLET MX(TCHASN, PF$TECHN, 8) = PF(LC06) // SAVE ASSIGNMENTS
TIN080 TEST E M(TCH1, PF$MOD, PF$SHIFT), &I, *+2 // ANY VALUE HERE?
BLET M(TCH1, PF$MOD, PF$SHIFT) = PF(TECHN) + TCHNS // NO; MUST BE FIRST
BLET M(TCH1, PF$MOD, PF$SHIFT) = PF(TECHN) + TCHNS // CURRENT = LAST
TEST E &MODID(PF$MOD), '0', TIN090 // SWING SHIFT?
BLET PF(PLOC) = PF(PLOC) + 1 // BUMP COUNTER

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
TIN090 SPLIT L.TCH000 //CREATE XACT
TEST E PF(PLOC)="2" //SECOND?
BLET PF(PLOC)=0 //YES;RESET
PRIORITY -1,YIELD //XACT GET THERE
PRIORITY 0
BLET PF(LOC1)=0 //ZERO OUT FOR NEXT READ
BLET PF(LOC2)=0 //ZERO OUT FOR NEXT READ
BLET PF(LOC3)=0 //ZERO OUT FOR NEXT READ
BLET PF(LOC4)=0 //ZERO OUT FOR NEXT READ
BLET PF(LOC5)=0 //ZERO OUT FOR NEXT READ
BLET PF(LOC6)=0 //ZERO OUT FOR NEXT READ
TRANSFER .TIN000 //LOOP AGAIN

* DONE INPUTING - INITIALIZ SYSTEM/CREATE REMAINING ACTIVE ENTITIES

DIN000 BCLOSE TECHS
WRITE MACRO TESTID,&TESTID
WRITE MACRO TESTDSR,&TESTDSR
BLET PF(LCTR)=&LBCTMAIN //TOTAL # LOAD BARS IN SYSTEM
TRANSFER .DIN10

* 572 INVENTORY

DIN010 TEST G &IN572(PFSENGINE) > 0 //ANY OF THIS ENGINE?
BLET &IN572(PFSENGINE)=&IN572(PFSENGINE) //YES;INIT
BLET &INV572(100)=&INV572(100)+&IN572(PFSENGINE)
SPLIT &IN572(PFSENGINE),0,FIN060 //ENGINE TO FINISHED
ENTER TOTALQ,&IN572(PFSENGINE)
PRIORITY -1,YIELD
PRIORITY 0
DIN020 LOOP ENGINESPF,DIN010 //KEEP LOOPING
WRITE MACRO INV572,.INV572(100) //INITIALIZE 
BARG MACRO INV572(100)
TRANSFER ,.DIN10

* 570 INVENTORY

DIN030 BLET PF(ENGINE)=99 //START 570 INITIALIZATION
DIN040 SPLIT &IN570(ENGINE) > 0,DIN030 //ANY OF THIS ENGINE?
BLET &IN570(ENGINE)=&IN570(ENGINE) //YES;INIT
BLET &INV570(100)=&IN570(100)+&IN570(ENGINE)
SPLIT &IN570(ENGINE),0,FN060 //ENGINE TO FINISHED
ENTER TOTALQ,&IN570(ENGINE)
PRIORITY -1,YIELD
PRIORITY 0
DIN050 LOOP ENGINESPF,DIN040 //KEEP LOOPING
TRANSFER ,.DIN10

ISP000 TERMINATE

DIN045 BLET PF(LCTR)=PF(LCTR)-PF(CTR) //CONSUME LOAD BARS
DIN050 BLET &INPROC=&INPROC-1 //COUNT IN PROCESS
ENTER EWIPQ
ENTER TOTALQ
ADVANCE .1
LOOP CTROPF,DIN045
TRANSFER ,.DIN060

DIN060 TRANSFER ,.TIN000 //MORE ENGINES

* 569 INVENTORY

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
BLET &DUM='569'
TRANSFER SBR,FNMOD, SUBRSFP
BLET PF(ENGINE)=0 //ENGINES
DIN070 BLET PF(ENGINE)=PF(ENGINE)+1
BLET PF(CTRL)=&SIN569(PFSENGINE) //#AVAILABLE
TEST G PF(CTRL),0,DIN090 //> 0?
BLET PF(LCTR)=PF(LCTR)-PF(CTRL)
DIN080 BLET &INPROC=&INPROC+1 //COUNT IN PROCESS
ENTER EWIPQ
ENTER TOTALQ
GATE SNF SP1
SPLIT 1,ITC000 //CREATE ENGINE
ADVANCE .1 //CLEARANCE
LOOP CTRSPF,DIN080
DIN090 TEST GE PFSENGINE, 99, DIN070 //MORE ENGINES

* 568 INVENTORY *

BLET &DUM='568'
TRANSFER SBR,FNMOD, SUBRSFP
BLET PF(ENGINE)=0 //ENGINES
DIN100 BLET PF(ENGINE)=PF(ENGINE)+1
BLET PF(CTRL)=&SIN568(PFSENGINE) //#AVAILABLE
TEST G PF(CTRL),0,DIN120 //> 0?
BLET PF(LCTR)=PF(LCTR)-PF(CTRL)
BLET PF(RJCT)=0 //ZERO OUT REJECT INDICATOR
TEST E &CTRIMIPFSENGINE),0,DIN110 //COMPRESSOR ENGINE?
TEST E &BTRIMIPFSENGINE),0,DIN110 //NO; BLUEBIRD?
BLET PF(RJCT)=1 //MUST BE REJECT
DIN110 BLET &INPROC=&INPROC+1 //COUNT IN PROCESS
ENTER EWIPQ
ENTER TOTALQ
GATE LC 260
SPLIT 1,ITRO00 //CREATE ENGINE
ADVANCE .1 //CLEARANCE
LOOP CTRSPF,DIN110
DIN120 TEST GE PFSENGINE, 99, DIN100 //MORE ENGINES

* MAIN XACT EXECUTES CLOCK *
* CLOCK MOVEMENT *
* DAY STARTS AT &CLKS *

CLK000 BLET &AMPM(1)='AM' //INITIALIZE AM/PM VAR
BLET &AMPM(2)='PM' //INITIALIZE AM/PM VAR
BLET PF1=&CLKS/60 //#HOURS INITIAL OFFSET
BLET PF2=&CLKS/600 //MINS. INITIAL OFFSET
BLET PF3=&CLKS/15 //CLOCK LOOPS
BLET PL1=PF1@12 //MODULUS OF 12
BLET PL2=PF2 //MAKE REAL #
TEST L PF3,48,CLK005 //START IN MORN OR AFTERNOON?
LOGIC C MORN //YES; MORNING
BLET PL3=(48-PF3)*15 //TIME AM/PM SWITCH
TRANSFER ,CLK010

CLK005 LOGIC S MORN //NO; AFTERNOON
BLET PL3=(56-PF3)*15
CLK010 BLET PF4=LS(MORN)+1 //AM/PM POINTER
WRITE MACRO DST. &AMPM(PF4) //AM/PM INDICATOR
BLET \( P_L 1 = \frac{(P_L 1)}{I_2+P_L 2/720} \times 130.85 \) // HOUR HAND OFFSET

BLET \( P_L 2 = \frac{(P_L 2/60)}{130.85} \) // MIN. HAND OFFSET

PLONAT MACRO 'HMD', 'TYYM', 'PL2' // INITIAL SET MINUTE HAND

PLONAT MACRO 'HHM', 'TYYM', 'PL1' // INITIAL SET MINUTE HAND

ADVANCE PL3 // INITIAL TIME TO AM/PM SW TCH

CLK020 LOGIC I MORN // INVERT AM/P M

BLET PF4=LS(MORN)+1 // AM/P M POINTER

WRITE MACRO D S T , & A M P M (P F 4 ) // AM/P M INDICATOR

ADVANCE 720 //NEXT 12 HRS

TRANSFER .CLK020

* MODULE OPERATION CONTROL

TMR000 TEST G &EFMIN(PF$MOD),0,TMRSTP // MOD IN OPERATION?

BLET PF(SHFT)=&MSHIFT(PF$MOD) // YES; GET INITIAL SHIFT

TEST NE PF(MOD),1,JOPO00

TEST NE PF(SHFT),0,TMRADV // ACTIVE SHIFT?

BLET PF(OPER1)=MH(TCH1,PF$MOD,PF$SHFT) // FIRST FACILITY

BLET PF(OPER1)=MH(TCH1,PF$MOD,PF$SHFT) // LAST FACILITY

FUNAVAIL PF(OPER1)-PF(OPERL) // SHUT EVERYONE OFF

BLET PF(CTR)=ACLKS/15-1 // STARTING SEGMENT

BLET PF(CTR)=FIN(PCNVRT) // CURRENT SEGMENT VALUE

TEST G PF(CTR),0,TMINT // CHECK FOR START/STOP

TEST LE PF(CTR),1,TMINT // IN OPERATION?

FAVAIL PF(OPER1)-PF(OPERL) // PUT IN PLAY

TRANSFER SBR,FACLR,SUBRSFP // CHANGE OPER COLORS

TMRADV ADVANCE 15 // TIME ADVANCE

TMR010 BLET PF(CTR)=PF(CTR)-1 // BUMP SEGMENT

BLET PF(CTR)=FIN(PCNVRT) // YES; RESET

TRANSFER ,FNITMDIR) // PROCEED

TMRINT TEST NE PF(CTR),2,TMRBEG // 0 START SHIFT

FAVAIL PF(OPER1)-PF(OPERL) // PUT IN PLAY

TRANSFER SBR,FACLR,SUBRSFP // CHANGE TECH COLORS

TRANSFER ,FNITMDIR) // PROCEED

* START OF SHIFT

TMRBEG TEST E &SDBY&WEK,3,0,1,2 // END OF WEEK?

TEST E &WDAAYS(PF$MOD),&WEK,TMRWKE // YES; WORK THE WEEKEND?

BLET &ACNOOP(PF$MOD)=&ACNOOP(PF$MOD)+&SALOW // START-UP

BLET &ACNOOP(PF$MOD)=&ACNOOP(PF$MOD)+&SALOW$PL // OPTIME

BLET PF(SHFT)=MH(HPS,PF(MOD),PF(CTR)) // CURRENT SEGMENT VALUE

ADVANCE &SALOW // DO STARTUP ALLOWANCE

BLET PF(SHFT)=PF(CTR) // CURRENT POSITION

TMR015 BLET PF(SHFT)=PF(SHFT)+1 // BUMP POINTER

TEST E PF(SHFT),97,0,2 // END OF ROAD?

BLET PF(SHFT)=1 // YES; REST TO 1

TEST G MH(HPS,PF$MOD,PF$SHFT),0,TMR015 // IN OPERATION?

TEST LE MH(HPS,PF$MOD,PF$SHFT),1,TMR015 // NOT A BREAK?

BLET PF(SHFT)=MH(HPS,PF$MOD,PF$SHFT) // FOUND NEXT SHIFT

TEST NE PF(MOD),1,JOPO10 // 564 MODULE

BLET PF(OPER1)=MH(TCH1,PF$MOD,PF$SHFT) // FIRST FACILITY

BLET PF(OPER1)=MH(TCH1,PF$MOD,PF$SHFT) // LAST FACILITY

FAVAIL PF(OPER1)-PF(OPERL) // START-UP

TRANSFER SBR,FACLR,SUBRSFP // CHANGE TECH COLOR

BLET &MD=PF(MOD) // SAVE MODULE

BLET &SF=PF(SHFT) // SAVE SHIFT

UNLINK I POOL,TMR030,ALL,BVSSTCO // SHIFT CHANGE-OVER

TMR020 ADVANCE 15-&SALOW // PROCEED

TRANSFER ,TMR010

TMR030 TEST E &MODID(PF$MOD),159,TMR040

SPLIT 1,ATS000 // DETERMINE ACTIVE CELLS

TRANSFER ,TCH400

TMR040 TEST E &MODID(PF$MOD),1599,TCH160

TEST NE PF(PLOC),2,TCH400
SPLIT 1,ATS000 //DETERMINE ACTIVE CELLS
TRANSFER ,TCH160
.
TMRBRK FUNAVAIL PF(OPERL)-PF(OPERL) //OPERATOR BREAK
TRANSFER SBR,FUNCLR,SUBRSPF //CHANGE TECH COLOR
TMR050 TEST E MH(HPS,PF(MOD),PF(CTR)),15,SBREK //MIN TMRBRK?
BLET &ACNOOP(PFSMOD)=&ACNOOP(PFSMOD)+15
ADVANCE 15 //DO 15 MIN. TMRBRK
BLET PF(CTR)=PF(CTR)+1 //BUMP SEGMENT
BLET PF(CTR)=PN(PCNVRT) //YES;RESET
TEST NE MH(HPS,PF(MOD),PF(CTR)),99,TMR055 //STILL ON BREAK?
TEST LE MH(HPS,PF(MOD),PF(CTR)),3,TMR050 //STILL ON BREAK?
TMR055 FUNAVAIL PF(OPERL)-PF(OPERL) //NO;BACK IN OPERATION
TRANSFER SBR,FACL,FACL,SUBRSPF
TRANSFER ,FN(TMOIR)
.
SBREK ADVANCE MH(HPS,PF(MOD),PF(CTR)) //SHORT TMRBRK
BLET &ACNOOP(PFSMOD)=&ACNOOP(PFSMOD)+15
ADVANCE 15-MH(HPS,PF(MOD),PF(CTR)) //RESUME
TRANSFER ,TMR100
.
TMREND TEST E &MODID(PFSMOD),‘569’,‘1’,‘2
UNLINK ACELLS,ACS100,ALL //ACTIVE CELLS
ADVANCE 15-&CALOW //CLEAN-UP ALLOWANCE
TEST NE PF(MOD),1,JOP130 /564 CONTROL?
UNLINK PDLAY,TMR100,ALL,MODSPF,PFSMOD //REORDER WAITING XACTS
UNLINK NOTCH,TMR100,ALL,MODSPF,PFSMOD //REORDER WAITING XACTS
LOGIC C MATCH
TEST NE &MODID(PFSMOD),‘569’,TMR091
BLET PF(LCTR)=PF(OPERL)-PF(OPERL)+1 //OPERATORS
BLET PFSINDX=PF(OPERL) //STARTING OPR. INDEX
TMR080 BLET PFSINDX=OPXID(PFSJINDX-TCHNS) //GET OBJECT ID
TEST G PF(INDX),0,TMR085
SCOLOR MACRO PFJINDX,‘BAC’
PRIORITY PF(JINDX),TMR200,CYCLESPL //INTERRUPT TECH IN ACTION
PRIORITY -1,YIELD
PRIORITY 0
RETURN PF(JNDX)
TMR085 BLET PFSJINDX=PFSJINDX+1 //BUMP POINTER
LOOP LCTRSPF,TMR080 //CONTINUE
UNLINK APQOL,TMR300,ALL,MODSPF,PFSMOD
UNLINK HOLD,TMR150,ALL //RELEASE HELD XACTS
TMR090 FUNAVAIL PF(OPERL)-PF(OPERL) //OPERATOR TMRBRK
ADVANCE &CALOW //DO CLEAN-UP
BLET &ACNOOP(PFSMOD)=&ACNOOP(PFSMOD)+&CALOW
MARK WAIT5PL //COLLECT STOPPAGE TIME
BLET PF(PTR)=0
TRANSFER ,TMR090
.
TMR091 BLET PF(JNDX)=PF(OPERL)
BLET PF(LCTR)=1
TRANSFER ,TMR080
.
* SHIFT CHANGE LOGIC
*
TMR100 LINK HOLD,FIFO //STAGE TEMPORARILY
TMR150 LINK NOTCH,FIFO //REORDER
*
TMR200 ALTERUENCE IMPRO,1,CYCLESPL,PLSCYCLE,CLOCSPF,PFSCLC
ALTERUENCE IMPRO,1,OPNUMSPF,PFSOPNUM,CLOCSPF,PFSCLC
REMOVE ATECH3
RELEASE PF(TECHN)+TCHNS //NO;RELEASE
BLET PL(CMPHER)=0
UNLINK IMPRO,TMR150,1,CLOCSPF,PFSCLC
PLON MACRO XIDL,TECHSTG
TMR300 LINK IPOOL,FIFO
*

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
TMRSWG UNLINK E APOOL, TCHS500, 1, TECHNSPF, (PFSOPER1-TCHNS). TMR400
TRANSFER, TMRAV
TMR400 ALTER E ATECHS, 1, OPER1, SPF-99, TECHNSPF, (PFSOPER1-TCHNS)
TRANSFER, TMRAV

* WEEKEND STOPPAGE *

TMRWKE BLET PF1=&SDAY
ADVANCE 1440
TEST NE PF1, &SDAY
TRANSFER, TMREG

* DETERMINE ACTIVE CELLS *

ATS000 BLET PF(LCTR) = 2 //CHECK 1ST 2 ANNS ONLY
ATS010 BLET PF(DELR0) = PF(20+PFSLCTR) //POINT TO POSSIBLE STA
TEST G PF(DELR0), 40, ATS020 //TEST CELL STATION
TEST LE PF(DELR0), 63, ATS020 //MAX. TEST CELL
SPLIT 1, ATS050
ATS020 LOOP LCTR$PF, ATS010
ATS030 TERMINATE

ATS050 GATE LC PF(DELR0), ATS030 //ALREADY ACTIVE?
LOGIC G PF(DELR0) //NO: NOW IS
GATE LS 81, . . .2
LOGIC C 81
GATE LS 87, . . .2
LOGIC C 87
BLET PF(DELR0) = PF(DELR0) - 40 //ADJUST POINTER
LINK ACELL$FIFO //ON ACTIVE CHAIN
ATS100 LOGIC C PF(DELR0) - 40 //RESET TO INACTIVE
TERMINATE

* TECHNICIAN COLOR SUBROUTINES *

FACLR TEST NE PF(MOD) .1, JOP120 //564?
BLET PF(LCTR) = PF(OPR1) - PF(OPR1) - 1 // # OPERATORS
BLET PF$JNDX = PF(OPR1) //STARTING OPR. INDEX
TEST G PF(INDEX), 0, CLR015
SCOLOR MACRO PF$JNDX, 'ACPR(PFSJNDEX-TCHNS)
CLR015 BLET PF$JNDX = PF$JNDX + 1 //BUMP POINTER
LOOP LCTR$PF, CLR010 //CONTINUE
TRANSFER, PF(SUBR) + 1 //RETURN

FUNCLR TEST NE PF(MOD) .1, JOP110 //564?
BLET PF(LCTR) = PF(OPR1) - PF(OPR1) - 1 // # OPERATORS
BLET PF$JNDX = PF(OPR1) //STARTING OPR. INDEX
CLR020 BLET PF$JNDX, 4, PF$JNDX - PFSJNDEX-TCHNS) //GET OBJECT ID
TEST G PF(INDEX), 0, CLR025
SCOLOR MACRO PF$JNDX, 'LAYOUT'
CLR025 BLET PF$JNDX = PF$JNDX + 1 //BUMP POINTER
LOOP LCTR$PF, CLR020 //CONTINUE
TRANSFER, PF(SUBR) - 1 //RETURN

TMRSWP TERMINATE //INACTIVE MODULE

* KEY OBJECT CREATION *

KEY000 BLET &KEYCNT = &KEYCNT + 1
CREATE MACRO KEY, XIDI
WRITE MACRO KEYID, XIDI, &CUSTMR(PFSLOC1)
SCOLOR MACRO XIDI, &ECLR(PFSLOC1)
BLET PF(LOC2) = 250 - (10 * &KEYCNT)
PLACEAT MACRO XIDI, 0, PFSLOC2
TERMINATE

* 564 SPECIAL CONTROL

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
```
JOP000  BLET  PF(OPER1) = 200  // FIXED 1ST
BLET  PF(OPERL) = 260  // FIXED LAST
BLET  PF(CTR) = &CLKS/15 + 1  // STARTING SEGMENT
BLET  PF(CTR) = FN(PCNVRT)
BLET  PF(CTR) = MH(HPS.PF(MOD), PF(CTR))  // CURRENT SEGMENT VALUE
FUNVAIL  PF(OPER1) - PF(OPERL)
SPSPD  MACRO  JH6,0
SPSPD  MACRO  JH7,0
SPSPD  MACRO  JSSP=JHSPD(1)  // INITIAL SPEED
TEST NE  PF(CTR), 0, TMRADV  // OFFSHIFT START
TEST LE  PF(CTR), 1, TMR(TMDIR)  // ON BREAK START
TEST LE  PF(CTR), 2, TMRBEG  // BEGINNING SHIFT START
FAVAIL  PF(OPER1) - PF(OPERL)  // ALL ELSE IN PLAY
PFIOPER1) = PFIOPERL)
JHK6,0
JHK7,0
transfer ,FN(TMDIR)
*  // LOOP PARAMETER
JOP010  BLET  PF(LCTR) = 260
FAVAIL  PF(OPER1) - PF(OPERL)  // PUT IN PLAY
JOP020  TEST GE  PF(LCTR), 212, JOP030
PREEMPT  PF(LCTR), JOP100.CYCLESPL  // PREEMPT & SAVE CYCLE
LOOP  LCTRSPF, JOP020
JOP030  PRIORITY = -1, YIELD
PRIORITY 0
BLET  PF(LCTR) = 260  // RETURN CONTROL
JOP040  TEST GE  PF(LCTR), 212, JOP050
RETURN  PF(LCTR)
JOP050  ALTERUCH NE 212, ALL, SHFTPF, PFSSHFT, SHFTPF, PFSSHFT
BLET  &CYADJ=JSSP/(&JHSPD(PFSSHFT))  // ADJUST TO NEW LS
UNLINK  212, JOP060, ALL
BLET  &SSP=JHSPD(PFSSHFT)
SPSPD  MACRO  JHK6, &SSP
SPSPD  MACRO  JHK7, &SSP
TRANSF  , TMR020  // RETURN
*  
JOP060  BLET  PL(CYCLE) = PL(CYCLE) * &CYADJ  // ADJUST TIME
TEST E  PL(TIME), 1, JHK035  // DIRECT ACCORDING TO STATUS
TRANSF  , JHK031
*  
JOP100  LINK  212, FIFO
*  
JOP110  ADVANCE 0
SPSPD  MACRO  JHK6, 0
SPSPD  MACRO  JHK7, 0
TRANSF  , PF(SUBR) + 1
*  
JOP120  ADVANCE 0
SPSPD  MACRO  JHK6, &SSP
SPSPD  MACRO  JHK7, &SSP
TRANSF  , PF(SUBR) + 1
*  
JOP130  ADVANCE 0
SPSPD  MACRO  JHK6, 0
SPSPD  MACRO  JHK7, 0
TRANSF  , TMR090
*  
*  INITIALIZATION STATUS
*  
ITT000  ENTER  SOUT
CREATE MACRO LBR.XIDL
SCOLOR MACRO XIDL, &ECLE(PFENGINE)
PLON MACRO XIDL, OUT
*  TRANSF  , ITT100
*  
ITC000  ENTER  SPL
CREATE MACRO LBR.XIDL
SCOLOR MACRO XIDL, &ECLE(PFENGINE)
```
PLON MACRO XIDI,PL
  * TRANSFER ,CN100
  *
ITR000 LOGIC S 260
  ENTER 260
  ENTER SPO
CREATE MACRO LBR,XIDI
TEST NE PF(ENGINE),0,ITR010
SCOLOR MACRO XIDI,&ECLR(PFSENGINE)
  * TRANSFER ,RPH001
ITR010 ADVANCE 0
SCOLOR MACRO XIDI,'WHITE'
  * TRANSFER ,RPH001
  *
ITE000 ENTER PF(CVSEC)
CREATE MACRO LBR,XIDI
PLON3 MACRO XIDI,P,PF(CVSEC)
  * TRANSFER ,EMP050

* CREATION OF ACTIVE TECHNICIAN XACTS
  *
TCH000 BLET &OPXID(PFSTECHN)=XID1 //SAVE XACT#
CREATE MACRO TECH,XIDI
WRITEO MACRO TID,XIDI,PF(TECHN)
PLON MACRO XIDI,TECHSTG
  TEST E PF(SHFT),&MSHIFT(PFSMOD),TCH010
  BLET &COPR(PFSTECHN)="LAY"
SCOLOR MACRO XIDI,'LAY'
  TEST NE PF(PC),2,TCH400 //2ND ASSIGNMENT
  SPLIT 1.ATS000 //ACTIVE CELL LOGIC
  LINK APOOL,FIFO //PLACE IN INACTIVE POOL
TCH010 BLET &COPR(PFSTECHN)="BAC"
SCOLOR MACRO XIDI,'BAC'
PLON MACRO XIDI,TECHSTG
  LINK IPOOL,FIFO //PLACE IN INACTIVE POOL
TCH100 SEIZE PF(TECHN)-TCHNS //GRAB OPERATOR
  BLET PF(OPNUM)=-1 //ASSIGNED
  JOIN ATECHS //IN ACTIVE GROUP
  TEST E PLICMPEST),0,-2
  BLET PLICMPEST)=PL(CYCLE)+AC1
  MARK WAITSP
  BLET PL(ACNBRK)=&ACNOOP(PFSMOD)
  BLET &COPR(PFSTECHN)="GREEN" //SET CURRENT COLOR
SCOLOR MACRO XIDI,'GREEN' //IN OPERATION
PLON3 MACRO XIDI,STA,PF(CLOC)
TCH110 TEST NE PF(CLOC),.PNTTC,TCH600 //NEW PAINT PROCESS?
  ADVANCE PL(CYCLE) //WORK ELEMENT
SCOLOR MACRO XIDI,'WHITE'
TCH115 BLET &COPR(PFSTECHN)="WHITE"
  TEST NE PLICMPEST),-1,TCH120 //HELPER DOESN'T ADJUST COUNT
  BLET &TECHC(PF$CLOC)=&TECHC(PF$CLOC)-1
  UNLINK INPRO,PRO220,1,CLOCSPF,PFS$CLOC //FREE ELEMENT
  PRIORITY -1,YIELD
TCH120 TEST NE PF(OPERl),-99,TCH500 //TAGGED TO MOVE?
  BLET PF(NOOPR)=PF(NOOPR)-20
  BLET ML(TECHBD,PFSTECHN,PFSNOOPR)=ML(TECHBD,PFSTECHN,PFSNOOPR)+PLSWAIT
  TEST NE PF(OPER1),-99,TCH500 //TAGGED TO MOVE?
TCH160 TEST NE CH(NOTCH),0,TCH300 //NO;ANY DELINQUENT UNITS?
  GATE LC MATCH
LOGIC S MATCH
BLET &LOC(1)=PF$LOC1
BLET &LOC(2)=PF$LOC2
BLET &LOC(3)=PF$LOC3
BLET &LOC(4)=PF$LOC4
BLET &LOC(5)=PF$LOC5
BLET &LOC(6)=PF$LOC6
* UNLINK NOTCH, PRO305, 1, BVDLAY1, , TCH120
BLET PF(LCTR)=6
TCH161 TEST G &LOC(PFSLCTR), 0, TCH162 //NON O LOC?
UNLINK NOTCH, PRO305, 1, CLOCSPF, &LOC(PFSLCTR), TCH162 //FIND MATCH LOC
BLET PL(CMPEST)=0 //ONE DISCOVERED
TRANSFER .TCH163 //GET OUT OF LOOP
TCH162 LOOP LCSTRSPF, TCH161
TRANSFER , TCH120
TCH163 GATE LC MATCH
UNLINK PDLAY, PRO310, 1, CLOCSPF, PF$LOC1, TCH170
BLET PF(OPNUM)=PF(LOC1)*1000
LINK APOOL, FIFO
TCH170 UNLINK PDLAY, PRO310, 1, CLOCSPF, PF$LOC2, TCH180
BLET PF(OPNUM)=PF(LOC2)*1000
LINK APOOL, FIFO
TCH180 UNLINK PDLAY, PRO310, 1, CLOCSPF, PF$LOC3, TCH190
BLET PF(OPNUM)=PF(LOC3)*1000
LINK APOOL, FIFO
TCH190 UNLINK PDLAY, PRO310, 1, CLOCSPF, PF$LOC4, TCH200
BLET PF(OPNUM)=PF(LOC4)*1000
LINK APOOL, FIFO
TCH200 UNLINK PDLAY, PRO310, 1, CLOCSPF, PF$LOC5, TCH210
BLET PF(OPNUM)=PF(LOC5)*1000
LINK APOOL, FIFO
TCH210 UNLINK PDLAY, PRO310, 1, CLOCSPF, PF$LOC6, TCH300
BLET PF(OPNUM)=PF(LOC6)*1000
TCH300 BLET PLCMPEST)=0 //ZERO OUT HELPER ID
TEST NE &MODEID(PFSMOD), '570', TCH550 //570 HELPS
TEST NE &MODEID(PFSMOD), '571', TCH550
TCH310 LINK APOOL, FIFO //BACK IN TECH POOL
* TCH320 LOGIC C MATCH //DELAY NOT FOUND
TRANSFER , TCH300 //GO BACK ON POOL
TCH400 LINK SWING, FIFO //STAGE 2ND OPS
TCH410 SPLIT 1, ATS000 //PUT INTO PLAY
TRANSFER , TCH160 //GO LOOK FOR WORK
* TCH500 UNLINK SWING, TCH410, 1, PLOCSPF, 2 //RELEASE ALTER EGO
SCOLOR MACRO XIDI, 'BAC'
PLON MACRO XIDL, TECHSTG
BLET PF(OPEECUR)=0 //RESET TAG
BLET PF(LCTR)=6 //SEARCH ASSIGNMENTS
TCH510 BLET PF(DUEL)=PF(PFSLCTR+20) //FIND ASSIGNMENT
TEST G PF(DUEL), 40, TCH520 //CHECK FOR CELLS & RTQ
TEST LE PF(DUEL), 63, TCH520
UNLINK ACCELLS, ATS100, 1, DELRTSPF, (PF$DELA-40)
TCH520 LOOP LCSTRSPF, TCH510
LINK IPOOL, FIFO //ORIGINAL GOES INACTIVE
* TECHNICIAN HELPING LOGIC
* TCH550 LOGIC C SMSTA
BLET PF(LCTR)=0 //ZERO FOR SEARCH
TCH560 BLET PF(LCTR)=PF(LCTR)-1
BLET PL(CMPEST)=0 //ZERO OUT
TEST LE PF(LCTR), 6, TCH310 //END OF SEARCH?
BLET &SVAR=FN(TLOC2) //NO; GET ELEMENT ASSIST#
TEST G &SVAR, 0, TCH560 //NOT ASSIGNED HERE?
SCAN A ATECHS, CLOCSPF, &SVAR, TECHSPF, CTRSPF, TCH560 //GET TECH#
SCAN E ATECHS, CLOCSPF, &SVAR, CMPESTPL, CMPESTPL
TEST G PL(CMPEST), 0, TCH560
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
PREEMPT P(FCTR)+TCHNS,TCH110,CYCLE$PL //DELAY TECH
SCAN E ATECHS,CLOC$PF,SVAR,CYCLE$PL,CYCLE$PL //REMAINING CYCLE
SCAN E ATECHS,CLOC$PF,SVAR,CLOC$PF,CLOC$PF //GROUP #
BLET PL(CYCLE)=PL(CYCLE)/2.0 //ADJUST
ALTER ATECHS.1,CYCLESPL,PLSCYCLE,CLOC$PF,SVAR //PASS CYCLE TIME
ALTER ATECHS.1,CMPEST$PL,0,CLOC$PF,SVAR //PASS CYCLE TIME
RETURN P(FCTR)+TCHNS
BLET PL(CMPEST)=-1
BLET P(FLOC)=SVAR
TRANSFER ,TCH100

* NEW PAINT PROCESS *

TCH610 BLET P(FLOC)=1 // 3 LOOPS
PLON MACRO XIDI,PFPASS
ADVANCE PL(CYCLE) //LOOP PAST TWO LOADS
LOOP LCRSPF,TCH610
PLON3 MACRO XIDI,STA,PF(CLOC)
SCOLOR MACRO XIDI, "WHITE"
TRANSFER ,TCH115

* PROCESS SUBROUTINES *

PRO000 BLET PF(LCTR)=0 //LOOP COUNTER TO 0
PRO100 BLET PF(LCTR)=PF(LCTR)-1 //BUMP
TEST LE PF(LCTR),6,PRO300 //END OF SEARCH?
TRANSFER ,FN(TLOC1)

PRO110 ADVANCE 0
FNDTCH MACRO LCO1SPF
TRANSFER ,PRO200

PRO120 ADVANCE 0
FNDTCH MACRO LCO2SPF
TRANSFER ,PRO200

PRO130 ADVANCE 0
FNDTCH MACRO LCO3SPF
TRANSFER ,PRO200

PRO140 ADVANCE 0
FNDTCH MACRO LCO4SPF
TRANSFER ,PRO200

PRO150 ADVANCE 0
FNDTCH MACRO LCO5SPF
TRANSFER ,PRO200

PRO160 ADVANCE 0
FNDTCH MACRO LCO6SPF

PRO200 BLET &TECH(PF$LOC)=&TECH(PF$LOC)-1 //FOUND TECH
PRO210 LINK INPRO,FIFO //IN PROCESS
PRO220 MARK WAITSPL //NO TECHS - COLLECT WAIT
BLET PL(ACMBRK)=&ACMOOP(PF$MOD) //ACCUM BREAK TIME
LINK NOTCH,FIFO //NO TECH CHAIN
PRO305 LOGIC C MATCH //1ST DELAY FOUND/FREE MATCH
* PRO305 SPLIT 1,NDL00
LINK PDLAY,FIFO //AWAIT 2ND CALL
PRO310 ALTERUCH E APOOL.1,CLOC$PF,PFS$LOC,OPNM$SPF,PF$LOC*1000 //PASS ID
ALTERUCH E APOOL.1,CYCLESPL,PLSCYCLE,OPNM$SPF,PF$LOC*1000 //PASS CYCLE
* ALTERUCH E APOOL.1,OPNM$SPF,PF$OPNM,CLOC$PF,PF$LOC //PASS OPNM
BLET PL(CMPEST)=PLSCYCLE+AC1 //ESTIMATE COMPLETION
UNLINK APOOL.TCH100.1,OPNM$SPF,PF$LOC*1000 //GET TECH
BLET PF(OPNM)=-1 //STOP PICKUP
TRANSFER ,PRO200

*--------------------------------------------------------------------------*

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
* ASSEMBLY LAUNCH

LIN000 SPLIT 1.CLBO00 //CREATE JHOOK LOAD BARS
BLET &J=0 //FOR SHIP SCHEDULE POINTER
BLET &SSP=JHSPD(1)
SPSPD MACRO JHK6,&SSP
SPSPD MACRO JHK7,&SSP

* READ SCHEDULE LINEUP IN

LIN010 BLET PF(SEQNM)=PF(SEQNM)+1 //BUMP SCHEDULE
TEST E MX(SHIPS,PFSEQNM,11,0,*,2) //SCHEDULE EOF?
BLET PF(SEQNM)=1 //YES;RESET TERMINATE
BLET PF(ENGINE)=MX(SHIPS,PFSEQNM,1) //GET ENGINE
BLET PF(TSEQN)=MX(SHIPS,PFSEQNM,4) //TRUCK
BLET PF(LCTR)=MX(SHIPS,PFSEQNM,2) //IN RUN
LIN020 BLET PF(SEQNM)=PF(SEQNM)-1 //GRAND SEQ.
GATE SE 200 //1ST OPEN
SPLIT 1.BLK000 //YES;CREATE BLOCK
GATE SNE 200 //WAIT FOR IT
LOOP LCTRSPF,LIN020 //CONTINUE W/ RUN
TRANSFER .LIN010 //GET NEXT RUN

* BLOCK LINE - DEPT. 566

BLK000 ENTER 200
LINK ASMLD.FIFO //WAIT ASSEMBLY LOAD
LDBLK LEAVE 200
TERMINATE

* J-HOOK ASSEMBLY LINE

CLBO00 BLET PF(LCTR)=&LBCTJHK //J-HOOK LOAD BARS
BLET PF(CVSEC)=9 //STARTING POINT
CLB010 GATE LC PF(CVSEC)-JHOOK //FIRST OPEN?
SPLIT 1.JHKO000 //CREATE CARRIER
ADVANCE .5 //DELAY
LOOP LCTRSPF,CLB010
TERMINATE

JHKO00 GATE LC PF(CVSEC)-JHOOK //CLEARANCE SECTION
LOGIC S PF(CVSEC)-JHOOK
ENTER PF(CVSEC)-JHOOK //ZONE
CREATE MACRO JHLB.XIDI
WRITEO MACRO JIDI,'EMPTY'
SCOLOR MACRO XIDI,'WHITE'
PLON3 MACRO XIDI,JHK,PF(CVSEC)

JHK010 ADVANCE 8.0/&FSP //CLEAR LOAD BAR
LOGIC C PF(CVSEC)-JHOOK
ADVANCE (&APATH(PFSCVSEC)-8.0)&/&FSP //TRAVEL
TEST LE PF(CVSEC),5,JHK020 //STILL ON FAST TRACK
SEIZE PF(CVSEC)-JHOOK //YES;GRAB STATION
ADVANCE PL(CYCLE)*&ASMMAX/&SSP //PROPORTION
RELEASE PF(CVSEC)-JHOOK

JHK020 BLET PF(PLOC)=PF(CVSEC) //UPDATE BLET PF(CVSEC)=PF(CVSEC)-1 //BUMP
TEST NE PF(CVSEC),10,JHK050 //END OF CONV.
TEST NE PF(CVSEC),8,JHK050 //END OF JHOOK?
GATE LC PF(CVSEC)-JHOOK //CLEARANCE SECTION
LOGIC S PF(CVSEC)-JHOOK //CLEARANCE SECTION
ENTER PF(CVSEC)-JHOOK //ZONE
LEAVE PF(PLOC)-JHOOK

PLON3 MACRO XIDI,JHK,PF(CVSEC)
TEST G PF(CVSEC),5,JHK010 //FAST TRACK?
TEST NE PF(CVSEC),6,JHK040 //AT SLOW CHAIN?
TEST NE PF(CVSEC),9,JHK010 //FAST RETURN CHECK

JHK030 BLET PL(CYCLE)=8.0/&SSP //CLEARANCE 8 SLOW
BLET PL(ITIME)=1
JHK031 ADVANCE PL(CYCLE)
LOGIC C PF(CVSEC)-JHOOK
BLET PL(CYCLE) = (&APATH(PFSCVSEC)-8.0)/&SSP //TRAVEL @ SLOW
BLET PL(ITIME) = 0
JHK035 ADVANCE &JHKO
TRANSFER ,JHK020 //KEEP LOOKING
.
JHK040 GATE LC 212
SELECT NU PTR$PF,212,260 //SELECT A FACILITY
SEIZE PF(PTR) //GRAB IT
JHKTOT BLET PL(CYCLE) = 14.0/&SSP //CLEARANCE @ SLOW
BLET PL(ITIME) = 1
TEST NE &EFAM(&ECLASI(PFENGINE)); &PRVENG,JHK031
JHKCHG ADVANCE &JHKCO
BLET &JHKO=TIM=2&JHKO
BLET &PRVENG= &EFAM(&ECLASI(PFENGINE))
TRANSFER ,JHK031
.
**TRANSFER TO MAIN CONVEYOR**
.
**JHK050 GATE LS (PF(CVSEC)-JHOOK), JHK055 //END OF LINE STOPPED?
**SpSpd MACRO JHK6,0
**SpSpd MACRO JHK7,0
**Logic S 212
**FinAvail 212-260 //STOP SLOW TRACK
**Gate LC PF(CVSEC)-JHOOK
**SpSpd MACRO JHK6,&SSP
**SpSpd MACRO JHK7, &SSP
**JHK054 Logic C 212
**JHK055 Gate LC PF(CVSEC)-JHOOK //CLEARANCE SECTION
**Logic S PF(CVSEC)-JHOOK
**Enter PF(CVSEC)-JHOOK //ZONE
**Leave PF(PLOC)-JHOOK
**Release PF(PTR)
**Plon3 MACRO XIDI,JHK, PF(CVSEC)
**Advance &APATH(PFSCVSEC)/&FSP //TRAVEL
**Gate LC 212
**Seize 210 //J-HOOK DELAY?
**Advance &JHKO= /&PERF(1) //UNLOAD TIME
**Release 210
**Blet &INPROC=&INPROC-1 //COUNT ENGINE IN PROCESS
**Blet &EPR(1)=&EPR(1)-1 //COUNT ENGINE RATE
**Blet &PR(1)=&PR(1)-1 //COUNT ENGINE RATE
**Barg MACRO RT1,TOP, &PR(1)
**Enter EWIPQ
**Enter TOTALQ
**Mark LAPTIMEPL //START TIMING
**Logic S ASML //SIGNAL UNLOAD
**Link ASML,FIFO //AWAIT INTERFACE
**ULasm Logic C PF(CVSEC)-JHOOK
**Scolor Macro XIDI,'WHITE'
**Write0 Macro JID,XIDI,'EMPTY'
**Transfer ,JHK020
.
**JHK060 Blet PF(CVSEC)=1 //AT FIRST
**Gate LC PF(CVSEC)-JHOOK //CLEARANCE SECTION
**Logic S PF(CVSEC)-JHOOK
**Enter PF(CVSEC)-JHOOK //ZONE
**Leave PF(PLOC)-JHOOK
**Plon3 MACRO XIDI,JHK, PF(CVSEC)
**Advance &APATH(PFSCVSEC)/&FSP //TRAVEL
**Gate SNE 200 //BLOCK THERE?
**Scanuch G ASMLD,SEQSNPF,0,SEQSNPF,SEQSNPF
**Scanuch E ASMLD,SEQSNPF,SEQSNPF,SEQSNPF,SEQSNPF
**Scanuch E ASMLD,SEQSNPF,SEQSNPF,SEQSNPF,SEQSNPF
**Scanuch E ASMLD,SEQSNPF,SEQSNPF,SEQSNPF,SEQSNPF
**Blet PL(CYCLE) = 440.0/&PER(1)/&EPR(1)
**Seize PF(CVSEC)-JHOOK
**Advance PL(CYCLE) * &ASMX//&SSP //UNLOAD TIME
RELEASE PF(CVSEC)+JHOOK
UNLINK ASMLD,DLBK.1     //GRAB BLOCK
SCOLOR MACRO XIDI, 'GREEN'
WRITEO MACRO JID,XIDI,&PARTNO(PFSENGINE)
LOGIC C PF(CVSEC)+JHOOK
TRANSFER .JHK020

' Initialize empty load bars in main loop.

CNV000 GATE SNF 18     //ZONE FULL?
SPLIT 1,CNV010        //NO;CREATE
ADVANCE .12     //CLEAR
LOOP LCTRSPF,CNVO00
TERMINATE

CNV010 ENTER 18
CREATE MACRO LBR,XIDI
WRITEO MACRO LBRID, XIDI, 'EMPTY'
SCOLOR MACRO XIDI, 'WHITE'
BARG MACRO PQ1,TOP,100.0*S(18)/(S(18)+R(18))

GOF1 ADVANCE 0
PLON MACRO XIDI,BB18
ADVANCE 11.22
GOFP2 ADVANCE 0
LINK 18,FIFO,GOFP2A
GOFP2A SEIZE SPF2
ENTER SPF2
PLON MACRO XIDI.PF2
ADVANCE .1
LEAVE SPF2
BARG MACRO PQ1,TOP,100.0*S(18)/(S(18)+R(18))
ADVANCE .94
GOFP3 RELEASE SPF2
UNLINK 18,GOFP2A,1
PLON MACRO XIDI.PF3
ADVANCE .90

ENTER SPL
LEAVE SPF2
PLON MACRO XIDI.PL
ADVANCE .17

' Now wait for a raw engine to be ready to be transferred.
' Wait on switch, while matching engine is transferred.

GAT LCF SPF1
GATE LS ASMUL.BLU100     //GO TEST BLUBIRD IF NO J-HOOK
GOFP4A GATE LS ASMUL     //AWAIT J-HOOK ENGINE?
SCANCHR G ASMUL.SSEQNSPF,0,SSEQNSPF,SSEQNSPF     //GET GRAND SEQ#
SCANCHR E ASMUL.SSEQNSPF,PF5SEQN,ENGINESPF,ENGINESPF     //GET ENGINE#
SCANCHR E ASMUL.SSEQNSPF,PF5SEQN,LAPTIMSPF,RELASTIMSPF
SCANCHR E ASMUL.SSEQNSPF,PF5SEQN,TSEQNSPF,TSEQNSPF
SCANCHR E ASMUL.SSEQNSPF,PF5SEQN,SEQNMSPF,SEQNMSPF
UNLINK ASMUL,ULASM,1     //RELEASE
LOGIC C ASMUL     //AWAIT NEXT ENGINE
WRITEO MACRO LBIRD,XIDI,&PARTNO(PFSENGINE)
SCOLOR MACRO XIDI.&ECLR1,PFSENGINE)

' MAIN DELIVERY CONVEYOR

GOFP5 SEIZE SPO
ENTER SPO
PLON MACRO XIDI.P0
ADVANCE .1
RELEASE SPO
LEAVE SPL
LOGIC C SPF1
ADVANCE .55
LINK 311,FIFO,CNV000
CNV020
SEIZE 211 // LEAK TESTER
BLET PF(RJCT)=0 // ZERO REJECT PARM
BLET PF(PCODE)=0 // ZERO OUT PROCESS CODE
TEST NE PF(DELRT),568,RPH000 // COMING FROM FLOOR
BLET PF(DELRT)=0 // ZERO OUT
TEST G &CTRIM(PFENGINE),0,CNV030 // BLUEBIRD?
BLET PF(PCODE)=PNTSYS // YES; DIRECT TO PAINT
TRANSFER ,CNV050 // PROCEED
CNV030
TEST G &CTRIM(PFENGINE),0,CNV040 // CARB TRIM
BLET &GBCNT(PFENGINE)=&GBCNT(PFENGINE)+1
BLET PF(CTR)+&GBCNT(PFENGINE) // SAVE
BLET PF(PORT)+&GBCNT(PFENGINE)*100
TRANSFER SBR.RPCT00.SUBR5PF // DETERMINE %
BLET PF(RJCT)=0 // NO REJECT TEST
BLET &GBCNT(1)=&GBCNT(1)+1 // REJECT COUNT
BLET PF(PORT)=&GBCNT(1) // SAVE COUNT
TRANSFER SBR.RPCT00.RPCT05PF // DETERMINE REJECT
TEST E PF(RJCT),0,RPH000 // PASS TEST?
TEST E PF(DELRT),0,RPH000 // YES; CARB TRIM JOB?
BLET PF(PCODE)=CLETST // REST TO TEST
CNV040
ADVANCE &LEAKTST(1)/&PERF(1) // NO LEAK TEST
BLET &GBCNT(1)=&GBCNT(1)+1 // REJECT COUNT
BLET PF(PORT)=&GBCNT(1) // SAVE COUNT
TRANSFER SBR.FMODM.SUBR5PF // FIND MOD #
BLET &DUM='569' // GOING 569
TRANSFER SBR.PFICVSEC // ZONE CLEAR
LOGIC S PF(CVSEC) // SHUT OFF
BLET &DUM='569' // GOING 569
ENTER PF(CVSEC) // MERGE ZONE
PLONJ
MACRO XID1.MBB.PF(CVSEC)
ADVANCE ML(CSECT.PFSCVSEC,12) // MERGE ZONE
LOGIC C PF(CVSEC) // CLEARANCE
LEAVE SPO // FREE PREVIOUS
RELEASE 211
UNLINK 211,CNV020,1
PLONJ
MACRO XID1.BB.PF(CVSEC)
TRANSFER ,BBDO10
* · BACKBONE DELIVERY CONVEYOR
* · -----------------------------------------
BBDO00
GATE LC PF(CVSEC) // SWITCH CLEAR
LOGIC S PF(CVSEC) // TIME
TEST NE &MBMO(PFSCVSEC),1,BBDO50 // MERGE ZONE?
ENTER PF(CVSEC) // NO; GET ZONE
PLONJ
MACRO XID1.BB.PF(CVSEC)
ADVANCE .12 // CLEARANCE ZONE
TEST E PF(CVSEC),.18,.*-2
TRANSFER SBF.BBDO90.SUBR5PF
LOGIC C PF(CVSEC) // OPEN CLEARANCE
LEAVE PF(PLOC) // FREE PREVIOUS
TEST E PF(PLOC),.3,.*-2
UNLINK PF(PLOC),BBDO00.1
TEST E PF(PLOC),.33,.*-2
UNLINK PF(PLOC),TLC3320.1
ADVANCE ML(CSECT.PFSCVSEC,1)-.12 // ZONE
BBDO10
TEST NE PF(CVSEC),.1,BBDO100 // GO TO RC?
TEST NE PF(CVSEC),.3,BBDO300 // ALL TEST CELLS
TEST NE PF(CVSEC),.4,BBDO400 // ALL TEST CELLS
TEST NE PF(CVSEC),.5,BBDO500 // TEST CELLS 7-18
* TEST NE PF(CVSEC),.9,BBDO900 // SPECIAL
* TEST NE PF(CVSEC),.11,BBDO100 // SPECIAL
TEST NE PF(CVSEC),.13,TLC800 // EXIT TEST CELL LOOP?
TEST NE PF(CVSEC),.16,BBD1600 // BACKBONE LIMIT CHECK
TEST NE PF(CVSEC),.17,BBD1700 // EXIT FOR PAINT, TRIM, EMPTIES
TEST NE PF(CVSEC),.18,GOFP2 // EMPTY LOADING RETURN
BBDO20
TRANSFER ,BBDO00
BBD050 ENTER PF(CVSEC) \(//\)MERGE ZONE

PL0N3 MACRO XIDI, BBM, PF(CVSEC)

ADVANCE ML(CSECT, PF(CVSEC), 1)

TEST E PF(CVSEC), 18, \*\*2

TRANSFER SBR, BBD090, SUBR/5PF

BBD055 LOGIC C PF(CVSEC) \(//\)CLEARANCE

LEAVE PF(PLOC), 3, \*\*2

TEST E PF(PLOC), BBD000, 1

UNLINK PF(PLOC), BBD000, 1

UNLINK PF(PLOC), TLC1320, 1

PL0N3 MACRO XIDI, B, PF(CVSEC)

BBD060 ADVANCE ML(CSECT, PF(CVSEC), 1) \(//\)ZONE TRAVEL

TRANSFER , BBD010

BBD090 LOGIC C BBSWT

UNLINK PF(PLOC), BBD1710, 1

LEAVE BACKBCNT

BARG MACRO PQ1, TOP, 100.0 \(/S(18) + (S(18) \times R(18))\)

TEST L S(\(\)BACKBCNT), \&BBLIM, PF(SUBR) - 1

LOGIC C BACKBCNT

TRANSFER , PF(SUBR) - 1

BBD0100 ENTER BACKUP

GATE LC RECR1 \(//\)GRAB SWITCH

LOGIC S RECR1

GATE SNF RECR10

TEST E BV(NOBACKUP), 1, \*\*2 \(//\)BACKUP CONDITION?

UNLINK BACKUP, RCL1005, 1

YES; RELEASE TO ATTIC

TEST E PF(PCODE), CLTEST, BBD0110

GATE SE RECR1, RCL1000

\(//\)ANYTHING IN ATTIC?

BBD0105 GATE LC COUNT, BBD0110

BBD0106 BLET XF(COUNT) = XF(COUNT) - 1

TEST GE XF(COUNT), \&MAX, \*\*2

LOGIC S COUNT

JOIN GCLTEST

BBD0110 GATE LC PF(CVSEC) - 1 \(//\)UPDATE

LEAVE BACKUP

LOGIC C RECR1

TRANSFER , BBD020

BBD0120 GATE GE RECR1, RCL1000

GATE SNF BACKUP, RCL1000

GATE SNF BACKUP

GATE LC COUNT

TRANSFER SIM, BBD0105, RCL1000

\(//\)RETEST IF TRUE/GO ATTIC IF NOT

BBD0300 BLET PF(PLOC) = PF(CVSEC)

BLET PF(CVSEC) = PF(CVSEC) - 1

\(//\)NEXT ZONE

LINK PF(PLOC), FIFO, BBD000

TRANSFER , BBD000

BBD0400 TEST E PF(PCODE), CLTEST, BBD020

TEST CELL CODE?

SCANN MIN GCLTEST, TSEQNSPF, TSEQNSPF, DEPRTSPF, CEL006

\/FIND LOWEST TRK GRID#?

TEST LE PFSTSEQNF, PPDELRTP, CEL006

\/AM I LOWEST?

TRANSFER , CEL006

BBD0500 TEST E PF(PCODE), CLTEST, BBD020

TEST CELL CODE?

GATE SNF 36, BBD020

\/ZONE CLEAR?

SCANN MIN GCLTEST, TSEQNSPF, TSEQNSPF, DEPRTSPF, CEL013

\/FIND LOWEST TRK GRID#?

TEST LE PFSTSEQNF, PPDELRTP, CEL013

\/AM I LOWEST?

TRANSFER , CEL013

BBD1600 LINK BACKBCNT, FIFO, BBD1610

\/ACCUMULATE BEHIND STOP

BBD1610 GATE LC BACKBCNT

\/STOP OPEN?

ENTER BACKBCNT

\(//\)GRAB ZONE

TEST GE S(BACKBCNT), \&BBLIM, BBD1620

LOGIC S BACKBCNT

BBD1620 \(\text{ADVANCE} \ 0.1\)
UNLINK BACKBCNT, BBD1610, 1
TRANSFER . BBD200

BBD1700 LINK PF(CVSEC), FIFO, BBD1710 // ACCUMULATE BEHIND STOPS
BBD1710 GATE LC BBSWT
LOGIC S BBSWT
TEST NE PF(PCODE), 0, BBD200 // EMPTY?
GATE SNF SSTG0 // NO; STAGE POSITION OPEN
GATE LC SSTG0 // YES; INDEX IN
LOGIC S SSTG0 // ONE AT TIME
ENTER SSTG0 // ENTER ZONE
PLON MACRO XIDI, STG0
ADVANCE .12 // INDEX IN
LOGIC C BBSWT
UNLINK PF(CVSEC), BBD1710, 1
LOGIC C SSTG0
LEAVE PF(CVSEC) // LEAVE PREVIOUS ZONE
LEAVE BACKBCNT // LEAVE BACKBONE
TEST L (BACKBCNT), &BBLIM, **2 // LESS THAN CHOKE LIMIT?
LOGIC C BACKBCNT // YES; FREE ZONE
ADVANCE .40 // INDEX
LINK SSTG0, FIFO, BBD1730
BBD1730 TEST NE PF(PCODE), PNTSYS, PST000 // DESTINED TO PAINT
TRANSFER . TRM000

* TEST CELL LEG *

TLC000 BLET PF(PLOC)=PF(CVSEC) // KEEP PREV
BLET PF(CVSEC)=31
TEST G PF(ENGINE), 0, TLC010 // EMPTY?
TEST G PF(PCODE), 10, TLC010 // 10.5/12.5?
BLET PF(PCODE)=PF(PCODE)-10 // YES; NOW AVAILABLE
JOIN PF(PCODE) // IN GROUP
TLC010 GATE LC PF(CVSEC) // SWITCH CLEAR
LOGIC S PF(CVSEC) // AT TIME
TEST NE &BBMRG(PFS.CVSEC), 1, TLC050 // MERGE ZONE?
ENTER PF(CVSEC) // NO; GET ZONE
PLON MACRO XIDI, TL, PFSCVSEC-30 // GET ON PATH
ADVANCE .13 // CLEARANCE ZONE
LOGIC C PF(CVSEC) // OPEN CLEARANCE
LEAVE PF(PLOC) // FREE PREVIOUS
TEST E PF(PLOC), .32, **2
UNLINK PF(PLOC), TLC3205.1
ADVANCE ML(CSECT, PFSCVSEC, 1) -.13 // ZONE
TLC020 TEST NE PF(CVSEC), .32, TLC3200 // GO TO RETORQ?
TEST NE PF(CVSEC), .33, TLC3100 // EXIT TL OR REPAIRS
TLC030 BLET PF(PLOC)=PF(CVSEC) // BUMP PREVIOUS LOC
BLET PF(CVSEC)=PF(CVSEC)+1 // NEXT ZONE
TRANSFER . TLC010

TLC050 ENTER PF(CVSEC) // MERGE ZONE
PLON3 MACRO XIDI, TL, PFSCVSEC-30
ADVANCE ML(CSECT, PFSCVSEC, 1) // MERGE ZONE
TLC055 LOGIC C PF(CVSEC) // CLEARANCE
LEAVE PF(PLOC) // FREE PREVIOUS
TEST E PF(PLOC), .32, **2
UNLINK PF(PLOC), TLC3205.1
PLON3 MACRO XIDI, TL, PFSCVSEC-30
TLC060 ADVANCE ML(CSECT, PFSCVSEC, 1) // ZONE TRAVEL
TRANSFER . TLC020

TLC3200 LINK PF(CVSEC), FIFO, TLC3205
TLC3205 GATE SNF RTORKO, TLC300 // ZONE FULL?
BLET PF(PLOC)=PF(CVSEC) // SAVE PREVIOUS LOCATION
TEST NE PF(ENGINE), 0, RTQ000 // EMPTY EXITS
TEST G PF(PCODE), REPAIRS, TLC300 // REPAIRS STAY ON LOOP?
TEST L PF(PCODE), 10, TLC300 // 1ST PASS 10.5/12.5 STAY ON
SCAN MIN PFSCODE, TSEQNSPF, TSEQNSPF, TSEQNSPF, DELRTSPF, TLC3210
TEST LE PFSTSEQN, PFSDELRT, TLC300

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
TLC3210 GATE SNF (294+PFSPCODE), TLC030
ENTER (294+PFSPCODE)
BARG4 MACRO PQ, (PFSPCODE-3), TOP, 100.0*S(294+PFSPCODE)/(S(294+PFSPCODE)+... R(294+PFSPCODE))
TRANSFER .ATQ000

TLC3300 BLET PF(PLOC)=PF(CVSEC) //SAVE PREVIOUS LOCATION
TEST E PF(PCODE), REPAIRS.TLC3310 //REPAIR PC?
GATE SNF REPQ, TLC3310
SCAN MIN GREPAIRS, TSEQNSPF, TSEQNSPF, DELRTSPF, RPR000
TEST LE PFSTSEQN, PFSDELAT, TLC3310
REMOVE GREPAIRS
TRANSFER .RPR000

TLC3310 ADVANCE .08
LINK PF(PLOC), FIFO, TLC3320
TLC3320 BLET PF(CVSEC)=3 //CONV. SECTION
GATE LC PF(CVSEC)
LOGIC S PF(CVSEC)
Enter PF(CVSEC)
PLON MACRO XIIDI.MBB3
ADVANCE .14
TRANSFER .BBDO55

* BLUEBIRD AND REAR PTO FLOOR QUEUE *

BLU000 ADVANCE 5 //5 MIN DELIVERY ASSUMED
QUEUE BLUBFQ //FLOOR QUEUE
BARG MACRO BBFG, RIGHT, Q(BLUBFQ)
WRITE MACRO BBFM, Q(BLUBFQ)
LOGIC S BLUBFQ //INDICATE HERE
LINK BLUBFQ.BIF0
BLU010 TEST E CH(BLUBFQ), 0, .2 //EMPTY YET?
LOGIC C BLUBFQ //BLUEBIRD NOT THERE?
DEPART BLUBFQ
BARG MACRO BBFG, RIGHT, Q(BLUBFQ)
WRITE MACRO BBFM, Q(BLUBFQ)
TERMINATE

BLU100 GATE LS BLUBFQ.GOPF4A //BLUEBIRD THERE?
TEST E BV(BMTR), 1, GOPF4A //YES, CONVEYOR FULL?
SCANCHG BLUBFQ, SEQSNSPF, 0, SSEQNSPF, SEQSNSPF //GET GRAND SEQ#
SCANCHG BLUBFQ, SEQSNSPF, PFSSSEQN, ENGINESPF, ENGINESPF //GET ENGINE#
SCANCHG BLUBFQ, SEQSNSPF, PFSSSEQN, LAPTMSPL, LAPTMSPL
SCANCHG BLUBFQ, SEQSNSPF, PFSSSEQN, TSEQNSPF, TSEQNSPF
SCANCHG BLUBFQ, SEQSNSPF, PFSSSEQN, SEQMSPF, SEQMSPF
UNLINK BLUBFQ, BLU010.1 //RELEASE
SCOLOR MACRO XIIDI, &ECLR1PFSENGINE
WRITE0 MACRO LBRID, XIIDI, &PART0(PFSENGINE)
BLET PF(DELRT)=568 //TAG TO GO TO 568
TRANSFER , GOPF5

* 568 REPAIR AND TRIM *

*RPH000 BLET &DUM='568' //NEW MODULE
TRANSFER SBR, FNDMOD, SUBRSNF //FIND CORRESPONDING #
GATE LC 260 //CLEARING ZONE
LOGIC S 260 //STOP
RELEASE 211 //FREE TEST ZONE
UNLINK 211, CVO20, 1
TEST E PF(RH100), 1, RPH000 //NEED REPAIR?
SCOLOR MACRO XIIDI, 'RED'
SELECT SNF CLCSNF, 261, 263 //OPEN REPAIR SPUR
RPH002 ENTER PF(CLOC)
PLON3 MACRO XIIDI, RS, PF(CLOC) -260
ADVANCE .28 //CLEARING
LOGIC C 260 //CLEARED
LEAVE SPO
ADVANCE 1.0 //TO SPUR

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
BLET CLЛЕAKР(СYCLE)=4ЛЕАКРPR(1) //REPAIR TIME
TRANSFER SBR,PRO000,SUBR$PF //PROCESS

SCOLOR MACRO XIDI,&ECLR(PFSENGINE)
GATE LC LEAKQ //EXIT CLEAR?
LOGIC S LEAKQ //YES:TIE UP
LEAVE PF(CLOC)

PLONMACRO XIDI,RF,PF(CLOC)-260
ADVANCE .14+.20*(263-PFSCLOC)
TRANSFER SBR,PROO00,SUBRSPF //PROCESS

APPH005 ENTER LEAKQ
LOGIC C LEAKQ

PLON MACRO XIDI,LEAKTQ
ADVANCE 1.38
LINK LEAKQ,FIFO.RPH010

RPH010 ENTER LKTST2 //LEAK TEST ZONE

PLON MACRO XIDI,LKT2 //PATH
ADVANCE .14
LEAVE LEAKQ
BLET PF(CLOC)=LKTST2 //NEW STATION
BLET CLЛЕAKР(СYCLE)=&LEAKTST(2)
TRANSFER SBR,PRO000,SUBR$PF //PROCESS
BLET PF(PCODE)=CLTEST //CELL TEST IS NEXT
BLET PF(DELAT)=0 //ZERO OUT DEL. ROUTE
BLET PF(PLOC)=270 //LEAK TEST #2
BLET PF(CVSEC)=19 //SET ZONE
GATE LC PF(CVSEC) //MERGE CLEAR
LOGIC S PF(CVSEC) //YES; TIE UP
ENTER PF(CVSEC)
BLET &DON='569'
TRANSFER SBR,FNDMOD,SUBRSPF
UNLINK LEAKQ,RPH010,1

PLON MACRO XIDI,BB19
ADVANCE .12
BLET &EPROD(2)=&EPROD(2)-1 //COUNT ENGINE IN PROCESS
LOGIC C PF(CVSEC) //CLEARANCE
LEAVE PF(CLOC)
ADVANCE .92 //CLEAR
BLET PF(PLOC)=PF(CVSEC)
BLET PF(CVSEC)=1
TRANSFER ,BBD000 //BACK TO MAIN

* BLUERES & COMPRESSOR TRIM

*----------------------------------------------

RPH100 ADVANCE 0

PLON MACRO XIDI,BCTRIMO
ADVANCE .38 //CLEARANCE
LOGIC C 260 //CLEAR ZONE
ENTER 271
LEAVE SPO

RPH110 ADVANCE 0

PLON MACRO XIDI,BCTRIM1
ADVANCE .79 //TIME
BLET PF(CLOC)=271 //START OF TRIM LINE
GATE LC PF(CLOC) //@ ASM STATION
LOGIC S PF(CLOC)
BLET CLЛЕAKР(СYCLE)=&BCTRIM(PFSENGINE)/6/&PERF(PFSMOD)
TEST E CLЛЕAKР(СYCLE),0,++,2 //NOT CARB?
BLET CLЛЕAKР(СYCLE)=&BCTRIM(PFSENGINE)/6/&PERF(PFSMOD)

RPH120 TRANSFER SBR,PRO000,SUBR$PF //PROCESS
BLET PF(PLOC)=PF(CLOC) //SAVE PREVIOUS
BLET PF(PLOC)=PF(CLOC)+1 //SUMP LOCATION
TEST NE PF(CLOC),277,RPH150 //END OF LINE?
ENTER PF(CLOC)

PLONMACRO XIDI,BCTRIM,PF(CLOC)-270
ADVANCE .15 //MOVE INTO NEXT
LOGIC C PF(PLOC)
LEAVE PF(PLOC)
GATE LC PF(CLOC) //STATION CLEAR
LOGIC S PF(CLOC) //TIE UP
TRANSFER ,RPH120

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
RPH150 GATE LC PF(CLOC)
LOGIC S PF(CLOC)
PLON MACRO XIDI.RBC
ADVANCE .14
LOGIC C PF(PLOC)
LEAVE PF(PLOC) //EXIT LINE
ADVANCE .14
GATE LC LEAKQ
LOGIC S LEAKQ
LOGIC C PF(PLOC)
TRANSFER .RPH005

RPH200 BLET PF(PLOC) = PF(CVSEC) //KEEP SEGMENT
GATE SF 271.RPH210 //QUEUE FULL?
BLET PF(CVSEC) = 1 //YES;RESET CONV. SEC
TRANSFER .BBD000 //BACK TO BACKBONE
RPH210 ENTER 271 //GET SEGMENT
GATE LC 260 //SEGMENT ZONE OPEN
LOGIC S 260
PLON MACRO XIDI,BCTRMM
ADVANCE .1
LEAVE PF(PLOC) //FREE BB
ADVANCE .19 //SWITCH IN
LOGIC C 260
TRANSFER .RPH110

* TEST RECIRCULATOR #1 *

RCL1000 TEST G &ATHEAD,0,RCL1005
TEST L PF(TSEQN),&ATHEAD,RCL1005 //LOWER TRUCK
LINK BACKUP.PFPC
RCL1005 BLET PF(PCODE) = RCRQ1
ENTER RCR1 //GRAB RC
BARG MACRO PQ2,TOP,100.0*S(RECR1)/(S(RECR1)+R(RECR1))
BLET PF(PCODE) = CLTEST
PLON MACRO XIDI,RC11
ADVANCE .12 //CLEAR SWITCH
LEAVE PF(CVSEC) //EXIT BB
LEAVE BACKUP //EXIT BACKUP
LOGIC C RCR1 //CLEAR ENTRY
ADVANCE 7.53 //UP THE VERTICAL
TEST E CH(RECR1),0,.*-2
BLET &ATHEAD=PF(TSEQN) //AT HEAD OF LINK
LINK RCR1,FIFO
RCL1010 LINK RCR10,FIFO,RCL1020 //YES;PUT BACK
RCL1020 ENTER RCR10
LEAVE RCR1
BARG MACRO PQ2,TOP,100.0*S(RECR1)/(S(RECR1)+R(RECR1))
PLON MACRO XIDI,RC12
BLET &ATHEAD=0
SCANUCH G RCR10,TSEQNSPF,0,TSEQNSPF,DELRTPF,RCL1030
TRANSFER .RCL1040
RCL1030 SCANUCH G RCR1,TSEQNSPF,0,TSEQNSPF,DELRTPF,RCL1050
RCL1040 BLET &ATHEAD=PF(DELRT)
RCL1050 BLET PF(DELRT) = 0
ADVANCE 1.3
BLET PF(CVSEC) = 1
GATE LC PF(CVSEC)
LOGIC S PF(CVSEC)
ENTER PF(CVSEC)
BLET XF(COUNT) = XF(COUNT) + 1
TEST GE XF(COUNT),&MAX,.*+2
LOGIC S COUNT
PLON MACRO XIDI.XBB2
ADVANCE .14
LEAVE RCR10
UNLINK RCR10,RCL1020,1
PLON MACRO XIDI.XBB2

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
LOGIC C PF(CVSEC)  
ADVANCE ML(CSELECT,PFSCVSEC,1) //ON BACKBONE  
JOIN GCLTEST  
TRANSFER .BBDO10

* TEST CELL LOGIC *

* 1ST BANK CELL *

CEL006 GATE SFN 34.CEL012  
SCANUCH LE ACELLS,DELRTSPF,6.,CEL012 //ANY ACTIVE HERE?  
TEST G &TCRTE(PFSENGINE),0,CEL010 //YES:ANY CELL WORK?  
TEST LE &TCRTE(PFSENGINE),6,CEL012 //NO;RIGHT RANGE?  
BLET PF(LOCI)=1 //YES:CLEARANCE INDICATOR  
ENTR 34  
LEAVE PFSCVSEC  
REMO GCLTEST  
BLET PF(CVSEC)=34  
PLON MACRO XID1,P34  
ADVANCE .33  
LINK 21,FIFO,FIRST

CEL010 GATE SFN 35.BBD020  
SCANUCH G ACELLS,DELRTSPF,6.,BBD020 //ANY ACTIVE HERE?  
TEST G &TCRTE(PFSENGINE),0,CEL020 //YES:ANY CELL WORK?  
TEST G &TCRTE(PFSENGINE),6,BBD020 //NO;RIGHT RANGE?  
BLET PF(LOCI)=7  
ENTR 35  //CAPTURE EXIT STORAGE  
LEAVE PFSCVSEC //LEAVE ZONE  
REMO GCLTEST  
BLET PF(CVSEC)=35  
PLON MACRO XID1,P35  
ADVANCE .38 //INDEX  
TRANSFER .CEL040

CEL013 GATE SFN 36.BBD020  
SCANUCH G ACELLS,DELRTSPF,6.,BBD020 //ANY ACTIVE HERE?  
TEST G &TCRTE(PFSENGINE),0,CEL030 //YES:ANY CELL WORK?  
TEST G &TCRTE(PFSENGINE),6,BBD020 //NO;RIGHT RANGE?  
BLET PF(LOCI)=7  
ENTR 36  //CAPTURE EXIT STORAGE  
LEAVE PFSCVSEC //LEAVE ZONE  
REMO GCLTEST  
BLET PF(CVSEC)=36  
PLON MACRO XID1,P36  
ADVANCE .62 //INDEX

* TEST CELL LOGIC *

CEL040 PRIORITY 10  
LINK 22,FIFO,FIRST  
FIRST GATE LC PFSCVSEC  
LOGIC S PFSCVSEC  
TEST G &TCRTE(PFSENGINE),0,TSC050 //GENERAL ASSIGNMENT?  
BLET PF(DELRT)=&TCRTE(PFSENGINE) //NO SPECIFIC  
TSC000 GATE FS PF(DELRT)+30 //GRAB CELL?  
GATE LS PF(DELRT)-30 //ACTIVE?  
TRANSFER SIM,TSC100,TSC000 //NO;PROCEED  
TSC050 TEST E PF(CVSEC),34,TSC080 //NOT;SPECIFIC 1ST DAY RANGE  
BLET PF(LOCI)=1 //1ST CELL  
BLET PF(LOC2)=6 //LAST CELL  
TRANSFER .TSC090 //YES;PROCEED  
TSC080 BLET PF(LOCI)=7 //1ST CELL  
BLET PF(LOC2)=13 //LAST CELL  
TSC090 SELECT E DELRTSPF,PF$LOC1,PF$LOC2,1,BV  
TEST E PF(DELRT),0,TSC100 //FOUND HOME?  
LOGIC S PF(LOCI)-80 //NO  
GATE LC PF(LOCI)-80 //AWAIT OPENING  
TRANSFER .TSC090  
TSC100 SEIZE PF(DELRT)+80 //ASSIGN CELL  
SEIZE FN7 //PATH WAY
LOGIC C PFSCVSEC
UNLINK FN2,FIRST,1 //TAKE NEXT
LEAVE PFSCVSEC //CLEAR ZONE
TEST NE PF(CVSEC).34,FBAYS
PLON3 MACRO XIDL,FR,PWSCVSEC
ADVANCE .12
FBAYS BLET XF(COUNT)=XF(COUNT)-1
TEST L XF(COUNT),&MAX,TSC102
LOGIC C COUNT
UNLINK BACKUP,BBD0106,1...,TSC101
TRANSFER ...,TSC102
TSC101 UNLINK RECr1,RLC101,1
TSC102 ADVANCE 0
PLON3 MACRO XIDL,IN,PF(DELRT)
ADVANCE FN4
RELEASE FN7
BLET PF(CLOC)=PF(DELRT)-40 //LOCATION - DO HOOK-UP
BLET PL(CYCLE)=(&HOOK (PFENGINE) +&HOO(PFENGINE))/&PERF(PFSMOD)
TRANSFER SBR,PRO000,SUBRSPF //HOOK UP
GATE LC PFSDELRT+451 //CELL DELAY UNDERWAY
.
* CELL DELAY TEST *
.
BLET &GBCNT(2)=&GBCNT(2)+1 //REJECT COUNT
BLET PF(CTR) = &GBCNT(2) //SAVE COUNT
BLET PF(PCT) = &CRPRRJ*100 //SAVE PCT
TRANSFER SBR,RPT00,SUBRSPF //DETERMINE REJECT
TEST NE PF(RJCT).0,TSC105 //NEED CELL REPAIR?
SCOLOR MACRO XIDL,'RED'
ADVANCE &CRPRRIM YES;DOWNTIME
SCLROR MACRO XIDL,&CLFL(PFENGINE)
TSC105 SEIZE PFSDELRT=100 RUN TIME STATISTICS
ADVANCE &CTEST(PFENGINE) -&HOOK(PFENGINE) /&PERF(PFSMOD) //TEST TIME
BLET ML(PROD,100.8)=ML(PROD,100.8)+1
RELEASE PFSDELRT=100 RUN TIME STATISTICS
* MAJOR REPAIR TEST 1ST *
.
TEST L PF(RETEST) =PF(RETST)+1 //BUMP COUNT
TEST E PF(RETEST).1,TSC110
BLET &ENG1(PFENGINE) = &ENG1(PFENGINE)+1 //REJECT COUNT
BLET PF(CTR) = &ENG1(PFENGINE) //SAVE COUNT
BLET PF(PCT) = &TRJRT1(PFENGINE)*100 //SAVE PCT
TRANSFER SBR,RPT00,SUBRSPF //DETERMINE REJECT
TRANSFER ...,TSC120
* MAJOR REPAIR TEST 2ND *
.
TSC110 BLET &ENG2(PFENGINE) = &ENG2(PFENGINE)+1 //REJECT COUNT
BLET PF(CTR) = &ENG2(PFENGINE) //SAVE COUNT
BLET PF(PCT) = &TRJRT2(PFENGINE)*100 //SAVE PCT
TRANSFER SBR,RPT00,SUBRSPF //DETERMINE REJECT
TSC120 TEST NE PF(RJCT).1,TSC200 //NEED CELL REPAIR?
BLET PF(RETEST)=0 //NO;ELIMINATE RETEST NEED
* MINOR REPAIR TEST *
.
BLET &GBCNT(3)=&GBCNT(3)+1 //REJECT COUNT
BLET PF(CTR) = &GBCNT(3) //SAVE COUNT
BLET PF(PCT) = &LRPRRJ*100 //SAVE PCT
TRANSFER SBR,RPT00,SUBRSPF //DETERMINE REJECT
TEST E PF(RJCT).0,TSC200 //NEED CELL REPAIR?
TSC130 BLET PF(RETEST)=0 //CLEAR PARMS
TSC200 MSAVEVALUE PROD,PFENGINE,PF(RETEST)+3,1,ML COLLECT TEST
MSAVEVALUE PROD,100,PF(RETEST)+3,1,ML //STATS
TEST E PF(RJCT).1,TSC210 //LAST PHASE
SCLROR MACRO XIDL,'RED'
TSC210 BLET PL(CYCLE)=&UNHK(PFENGINE) /&PERF(PFENGINE)
TRANSFER SBR,PRO000,SUBRSPF //HOOK UP
SEIZE FN11 //EXIT PATH CLEAR
PLON3 MACRO XIDL,OUTB,PF(DELRT)

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
ADVANCE .14
RELEASE PF(DLRT) = 80 //RELEASE CELL
LOGIC C PF(LOC1) = 80 //SIGNAL OPENING

PLON3 MACRO XID1.OUT, PF(DLRT)
ADVANCE FN5
BLET PF(CVSEC) = FN3 //32 OR 33
BLET PF(PCODE) = CSTRIM //DEFAULT TO CUSTOM TRIM
TEST E &TCOA(PFSENGE) .0 ,*-2 //ANY PAINT STD?
BLET PF(PCODE) = FNTRIM //NO; PC=FINAL TRIM
TEST E PF(RJCT) .1 , TSC215 //REJECT?
BLET PF(PCODE) = REPAIRS //YES; ROUTE TO REPAIRS
TRANSFER .TSC220
TSC215 ENTER TSTLCOUT
BARG MACRO PQ3.TOP, 100.0 *S(TSTLCOUT) / (S(TSTLCOUT) - R(TSTLCOUT))
TEST E BV(ENG105) .1 , TSC220 //10.5/12.5 S?
BLET PF(PCODE) = PF(PCODE) - 10 //YES; RESET PROCESS CODE
TSC220 GATE LC 80 //METER
LOGIC S 80 //CLOSE OFF
GATE LC PF(CVSEC) //CLEARANCE
LOGIC S PF(CVSEC) //ZONE CLEAR
ENTER PF(CVSEC)

PLON3 MACRO XID1.XTL, (PF$CVSEC-30)
ADVANCE XL(CSECT, PF$CVSEC, 12)
RELEASE FN11 //EXIT
LOGIC C 80

TEST L ?F(PCODE), 10,'-2 //10.5-12.5 DON'T JOIN HERE
JOIN ?F(PCODE) //JOIN GROUP
TRANSFER .TLC060 //ENTER CONV. LOOP

* RETORQUE AREA
*

RTQ000 GATE LC RTORKQ //RETOURQUE QUEUE
LOGIC S RTORKQ
ENTER RTORKQ
REMOVE PF(PCODE)
TEST NE BV(RTQBYP) .1 , RTQ010 //EMPTY OR PAINT?
LEAVE TSTLCOUT
BARG MACRO PQ3.TOP, 100.0 *S(TSTLCOUT) / (S(TSTLCOUT) - R(TSTLCOUT))
RTQ010 ADVANCE 0
PLON MACRO XID1.RTQ
ADVANCE .12
LEAVE PF(PLOC) //FREE RETORQUE INPUT
LOGIC C RTORKQ
UNLINK PF(PLOC), TLC1205.1
ADVANCE .75
BLET PF(PLOC) = 37
LINK RTORKQ, FIFO, RTQ050
RTQ050 TEST NE BV(RTQBYP) .1 , RTQ100 //BYPASS?
SELECT LC CVSEC$PF, 38, 39 //PICK PATH
LOGIC S PF(CVSEC)
TEST NE BV(RTQL) .1 , *-2
UNLINK RTORKQ, RTQ050.1
PLON3 MACRO XID1.RTQ, (PF$CVSEC-37)
ADVANCE .15 //CONV. TRAVEL
LEAVE PF(PLOC) //STOP 20 REOPENED
ADVANCE XL(CSECT, PF$CVSEC, 1) //QUEUE POSITION
ENTER PF(CVSEC)

PLON3 MACRO XID1.HTS, (PF$CVSEC-37)
ADVANCE .14 //MOVE IN
LOGIC C PF(CVSEC)
UNLINK RTORKQ, RTQ050.1 //MAKE OPENING
BLET PF(PLOC) = PF(CVSEC) + 23 //STATION ID 61/62
BLET PLCYCLE = &TRORK(PFSENGE) / &PERF(PF$MOD) / 2.0
TRANSFER SBR.PROOC00, SUBR$PF //PROCESS

SCOLOR MACRO XID1.ECLR(PFSENGE)
BLET PF(PLOC) = PF(CVSEC) //SAVE LOCATION
BLET PF(CVSEC) = 40 //BUM LOCATION

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
GATE LC PF(CVSEC)
LOGIC S PF(CVSEC)
ENTER PF(CVSEC)
ADVANCE .12
LOGIC C PF(CVSEC)
LEAVE PF(PLOC)
ADVANCE ML(CSECT,PF$PLOC,11)-.12 //REMAINING TRAVEL
BLET PF(PLOC)+PF(CVSEC)
BLET PF(CVSEC)=15
BLET &EPROD(3)=&EPROD(3)+1 //COUNT ENGINE IN PROCESS
BLET &PRORATE(2)=&PRORATE(2)+1 //COUNT ENGINE RATE

BARG MACRO RT2, TOP, &PRORATE(2)
BLET &DIM='570'
TRANSFER SBR, FNDMOD, SUBR$PF
GATE LC PF(CVSEC)
LOGIC S PF(CVSEC)
ENTER PF(CVSEC)

PLON3 MACRO XDI1, MBP, PF(CVSEC)
ADVANCE ML(CSECT, PFS$CVSEC, 12) //MERGE ZONE
TRANSFER .BBDO55 //RETURN TO BB

* 569 REPAIRS

*--------------------------*
RPR000 GATE LC REPQ
LOGIC S REPQ
ENTER REPQ

PLON MACRO XDI1, RPQ
ADVANCE .12
LEAVE PF(PLOC)
LOGIC C REPQ
ADVANCE .56

RPR005 SELECT NJ CVSEC$PF, 119, 122 //OPEN SPUR
TEST E PF(CVSEC), 0, RPR010
LINK 34, FIFO //AWAIT

RPR010 SEIZE PF(CVSEC) //GET SPUR
ENTER EREPR //EXIT PATH

PLCN3 MACRO XDI1, IN, PF(CVSEC)
ADVANCE .1 //CLEARANCE
LEAVE REPQ //FREE QUEUE
ADVANCE .2 //REMAINING PATH
LEAVE EREPR //CLEAR PATH
BLET PF(PLOC)=PF(CVSEC)-118-265 //LOCATION
TEST E PF(RETEST), 0, RPR050 //MAJOR REPAIR?
BLET PL CYCLE)=-LRPRTIM //TIME
BLET PF(PCODE)=$CSTRIM //DEFAULT TO CUSTOM TRIM
TEST E &TCOAT(PF$ENGINE), 0, *=2 //ANY PAINT STD?
BLET PF(PCODE)=$FTRIM //NF; PC=FINAL TRIM
TRANSFER .RPR100

RPR050 BLET PL CYCLE)=-HRPRTIM //HEAVY REPAIR
BLET PF(PCODE)=CLTEST

RPR100 TRANSFER SBR, PRO000, SUBR$PF //PROCESS TIME
BLET PF(RJCT)=0 //NOT REJECT

SCOLOR MACRO XDI1, &ECLR(PF$ENGINE)
ENTER EREPR //PATH CLEAR?

PLON3 MACRO XDI1, OUTB, PF(CVSEC) //YES
ADVANCE .09 //BACKOUT
RELEASE PF(CVSEC) //FREE SPUR

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
UNLINK 14,RPR005,1  //TAKE NEXT
PLON3 MACRO XIDI,OUT,PF(CVSEC)  //OUTBOUND PATH
ADVANCE .3
TEST NE PF(PCODE),CLTEST,RPR110
XXX002 ENTER TSTLCOUT
BARG MACRO PQ3,TOP,100.0*STSTLCOUT/(S(TSTLCOUT)+R(TSTLCOUT))
RPR110 BLET PF(PLOC)=259  //EXIT PATH
BLET PF(CVSEC)=4  //BACKBONE ENTRY
GATE LC PF(CVSEC)
LOGIC S PF(CVSEC)
ENTER PF(CVSEC)
TEST E PF(PCODE),CLTEST,RPR150
BLET XF(COUNT)=X(COUNT)+1
TEST GE XF(COUNT)\#MAX,\#2  //COUNT OUT
LOGIC S COUNT
RPR150 JOIN PF(PCODE)  //JOIN NEXT GROUP
PLON3 MACRO XIDI,MBB,PF(CVSEC)
ADVANCE ML(CSSEC,PFS(CVSEC),12)  //MERGE ZONE
TRANSFER BBD055  //RETURN TO 3BB

* TRIM CONVEYOR
*------------------
TRM000 GATE LC STRM1  //INPUT ZONE
LOGIC S STRM1  //SHUT OFF ZONE
ENTER STRM1  //ENTER ZONE
PLON MACRO XIDI,TRMI
ADVANCE .12  //INDEX IN
LOGIC C STRM1  //CLEAR
LEAVE SSTG0  //FREE STAGE
UNLINK SSTG0,BBD1730,1
ADVANCE 1.87
BLET PF(CVSEC)=PF(PCODE)*20  //TRIM ZONE
LINK STRM1,FIFO,TRM020
TRM020 ENTER PF(CVSEC)
ENTER STRM1
PLON MACRO XIDI,TRMI
ADVANCE .23
LEAVE STRM1
UNLINK STRM1,TRM020,1
TRM030 TEST E PF(PCODE),CSTRIM,FNT000  //CUSTOM OR FINAL

* CUSTOM TRIM
*------------------
PLON MACRO XIDI,CTI
ADVANCE 2.15
BLET PF(PLOC)=PF(CVSEC)
BLET PF(INDX)=1
BLET PF(CVSEC)=PF(CVSEC)+1
LINK PF(CVSEC),FIFO,CST000
CST000 ENTER PF(CVSEC)
PLON3 MACRO XIDI,CT,PF(INDX)
ADVANCE .12
LEAVE PF(PLOC)
LEAVE CSTRMCNT
BARG MACRO PQ4,TOP,100.0*SCSTRMCNT/(S(CSTRMCNT)+R(CSTRMCNT))
ADVANCE .15
CST010 TEST LE PF(INDX),CSTLS,CST020
BLET PF(CLOC)=CSTRMI-1+PF(INDX)  //POSITION
BLET PL(CYCLE)=ML(CSTRMCNT,ECLASSI,PFENGINE),PF$INDEX)\&PERF\#PF$MOD
TEST G PL(CYCLE),0,CST020
TRANSFER SGR,PRO000,.SUBRPF
CST020 BLET PF(PLOC)=PF(CVSEC)
BLET PF(PCODE)=PF(PCODE)+1
BLET PF(CVSEC)=PF(CVSEC)+1
ENTER PF(CVSEC)
LEAVE PF(PLOC)
PLON3 MACRO XIDI,CT,PF(INDX)
TEST E PF$INDEX,2,CST030

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
UNLINK PFSPLOC,CST000,1
CST030 TEST NE PF(CVSEC),149,CST110
  ADVANCE .27
  TRANSFER .CST010

  CST110  ADVANCE .93
  BLET PF(PCODE)=PNTSYS
  TEST G &BTRIM(PFSENGINE),0,*+2
  BLET PF(PCODE)=FNTRIM
  LINK PF(CVSEC),FIFO,CST120
CST120 ENTER (294+PFSPCODE)
  BARG4 MACRO PQ,(PFSPCODE-3).TOP,100.0*S(294+PFSPCODE)/(S(294+PFSPCODE)-R(294+PFSPCODE))
  BLET &PRORATE(3)=&PRORATE(3)+1 //COUNT ENGINE IN PROCESS
  BARG MACRO RT3,TOP,&PRORATE(3)
  GATE LC TRMOUT
  LOGIC S TRMOUT
  ENTER TRMOUT
PLON MACRO XIDI,TRMOM
  ADVANCE .12
  LEAVE PF(CVSEC)
  BLET &EPROD(4)=&EPROD(4)+1 //COUNT ENGINE IN PROCESS
  UNLINK PF(CVSEC),CST120,1
TRM100 LOGIC C TRMOUT
PLON MACRO XIDI,TRMO
  ADVANCE 1.39
  BLET PF(PLOC)=158 //EXIT PATH
  BLET PF(CVSEC)=17 //BACKBONE ENTRY
  GATE LC PF(CVSEC)
  LOGIC S PF(CVSEC)
  ENTER PF(CVSEC)
  ENTER BACKBCNT //BACKBONE ZONE
  TEST GE $1(1BACKBCNT),&BBLIM,**2 //AT CHOKE LIMIT
  LOGIC S BACKBCNT //CLOSE OFF ZONE
PLON3 MACRO XIDI,MDB,PF(CVSEC)
  ADVANCE .12
  LEAVE PF(CVSEC)
  BLET PF(CVSEC)=PF(CVSEC)+1
  ENTER PF(CVSEC)
  LEAVE PF(CVSEC)
  LEAVE FNTRMCNT
BARG MACRO PQ5,TOP,100.0*S(FNTRMCNT)/(S(FNTRMCNT)-R(FNTRMCNT))
  ADVANCE .15
FNT020 TEST NE PF(DELRT),.99,FNT030
  TEST LE PF(INDX),&FNTLS,FNT030
  BLET PF(CLOC)=FTRIM1-1+PF(INDX) //POSITION
  BLET PL(CYCLE)=ML(FNLTRM,&ECLASI(PFSENGINE),PFSINDX)/&PERF(PFSMOD)
  TEST G PL(CYCLE),.0,FNT030
  TRANSFER SBR,FNO000,SUBRSPF
FNT030 BLET PF(PLOC)+PF(CVSEC)
  BLET PF(INDX)+1
  BLET PF(CVSEC)=PF(CVSEC)+1
  ENTER PF(CVSEC)
  LEAVE PF(PLOC)
PLON3 MACRO XID1,PF(INDX)
  TEST E PFSINDX,2,FNT040
  TRANSFEN PFSPLOC,FNT040,1

* FINAL TRIM *

FNT000 BLET &DOM='571'
  TRANSFER SBR,FNMOD,UBRSPF
PLON MACRO XIDI,FT0
  ADVANCE 1.58
  BLET PF(PLOC)=PF(CVSEC)
  BLET PF(INDX)=1
  BLET PF(CVSEC)=PF(CVSEC)+1
  LINK PF(CVSEC),FIFO,FNT010
FNT010 ENTER PF(CVSEC)
PLON3 MACRO XIDI,FT,PF(INDX)
  ADVANCE .12
  LEAVE PF(PLOC)
  LEAVE FNTRMCNT
BARG MACRO PQ5,TOP,100.0*S(FNTRMCNT)/(S(FNTRMCNT)-R(FNTRMCNT))
  ADVANCE .15
FNT020 TEST NE PF(DELRT),.99,FNT030
  TEST LE PF(INDX),&FNTLS,FNT030
  BLET PF(CLOC)=FTRIM1-1+PF(INDX) //POSITION
  BLET PL(CYCLE)=ML(FNLTRM,&ECLASI(PFSENGINE),PFSINDX)/&PERF(PFSMOD)
  TEST G PL(CYCLE),.0,FNT030
  TRANSFER SBR,FNO000,UBRSPF
FNT030 BLET PF(PLOC)+PF(CVSEC)
  BLET PF(INDX)+1
  BLET PF(CVSEC)=PF(CVSEC)+1
  ENTER PF(CVSEC)
  LEAVE PF(PLOC)
PLON3 MACRO XID1,PF(INDX)
  TEST E PFSINDX,2,FNT040
  UNLINK PFSPLOC,FNT040,1

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
FNT040 TEST NE PF(CVSEC),169,FNT110
ADVANCE .27
TRANSFER .FNT020

FNT110 ADVANCE .13
BLET PF(CLOC)=FTRIM1-1+PF(INDX) //POSITION
BLET PL(CYCLE)=ML(FNLTRM,&ECLASI(PF$ENGINE),PF$INDEX)/&PERF(PFSMOD)
TEST G PL(CYCLE),0,FNT120
TRANSFER SBR,PRO0000,SUBR$PF

FNT120 SPLIT 1,FNIN000 //SEND TO INSPECTION
SCOLOR MACRO XIDI,'WHITE'
WRITEO MACRO LBRID,XIDI,'EMPTY'
BLRT &PRORATE(4) //COUNT ENGINE IN PROCESS
BARG MACRO RT4, TOP,&PRORATE(4)
BLET PF(ENGINE)=0
BLET PF(PCODE)=0
ENTER TRMOUT
GATE LC TRMOUT
LOGIC S TRMOUT
PLON MACRO XIDI,MTRMO
ADVANCE .23
LEAVE PF(CVSEC)
TRANSFER .TRM100

* PAINT SYSTEM

PST000 GATE LC SPNT1 //ENTER PAINT
LOGIC S SPNT1
ENTER SPNT1
BLET &DUM='570P'
TRANSFER SBR,FNT000,SUBR$PF
PLON MACRO XIDI,PNT1
ADVANCE .12 //CLEAR LIMIT
LEAVE SSTG0
LOGIC C SPNT1
UNLINK SSTG0,BBD1730,1
ADVANCE 2.15

* Washer process chain.

PST010 GATE LC SPNT2 //TRANSITION TO PROCESS CHAIN
LOGIC S SPNT2
PLON MACRO XIDI,PKFR
ADVANCE .13
ENTER SPNT2
LEAVE SPNT1 //FREE INPUT QUEUE
LEAVE PAINTCNT
BARG MACRO PQ6, TOP.100.0*S(PAINTCNT)/(S(PAINTCNT)+R(PAINTCNT))
PLON MACRO XIDI,PNT2
ADVANCE 8.02/&PNTSSP //TIME TO INDEX INTO PAINT
LOGIC C SPNT2
UNLINK SPNT1,PST010,1
ADVANCE 49.70/&PMTSSP //REMAING TRAVEL
GATE LC SPNT3 //TRANSITION TO PROCESS CHAIN
LOGIC S SPNT3
ENTER SPNT3
PLON MACRO XIDI,PNT3
ADVANCE .12
LEAVE SPNT2
LOGIC C SPNT3
ADVANCE .25 //TIME TO INDEX INTO PAINT
GATE LC SPNT4 //TRANSITION TO PROCESS CHAIN
LOGIC S SPNT4
BLET PF(CLOC)=PMASK
BLET PL(CYCLE)=(&MASK(PF$ENGINE)+&BLOWO(PF$ENGINE))/&PERF(PFSMOD)
TRANSFER SBR,PRO0000,SUBR$PF
SPLIT 1,PST100 //THROUGH PREP

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
LOGIC C SPNT4
LINK SPNT3,FIFO
PST020 ENTER SPNT4
LEAVE SPNT3
PLON MACRO XIDI,PNT4
ADVANCE .20 //TIME TO INDEX INTO PAINT
BLET PF(CLOC)=PPRIM
GATE SF SPNT5,PST030 //SECOND STOP OPEN?
BLET PF(CLOC)=0 //NO TAG AS SECOND LOAD BAR
LINK SPNT4,FIFO
PST030 ENTER SPNT5 //Enter initial section of oven.
LEAVE SPNT4
PLON MACRO XIDI,PNT5
ADVANCE .14 //Delay for path time.
TEST NE PF(CLOC),0,PST040
BLET PF(CLOC)=PNTTC
BLET PL(CYCLE)=5.0
TRANSFER SBR,PRO000,SUBRSPP
GATE LC 464 //PAINT DELAY UNDERWAY
UNLINK SPNT4,PST030,1
PST040 MARK DELAYSPL //START FLASHOFF TIME
ENTER SPNT6
LEAVE SPNT5
TEST E PF(CLOC),0,*+2
SPLIT 1,PST100
PLON MACRO XIDI,PNT6
ADVANCE 1.5 //TRAVEL TIME
LINK SPNT6,FIFO,PST042
PST042 GATE LC SPNT6 //CAPTURE EXIT STOP
LOGIC S SPNT6
BLET PL(CYCLE)=&FLASH-MPSDEAYSPL //AWAIT FLASH-OFF
TEST G PL(CYCLE),0,*+2
ADVANCE PL(CYCLE) //AWAIT FLASH-OFF
*
* Oven.
*
ENTER SPNT7
LEAVE SPNT6
LOGIC C SPNT6
UNLINK SPNT6,PST042,1
MARK DELAYSPL //START OVEN TIME
PLON MACRO XIDI,PNT7
ADVANCE .69
LINK SPNT7,FIFO,PST044
PST044 GATE LC SPNT7 //CAPTURE EXIT STOP
LOGIC S SPNT7
BLET PL(CYCLE)=&TIMEOVEN-MPSDEAYSPL //AWAIT BAKE
TEST G PL(CYCLE),0,*+2
ADVANCE PL(CYCLE) //AWAIT OVEN TIME
ENTER SPNT8
LEAVE SPNT7
LOGIC C SPNT7
UNLINK SPNT7,PST044,1
MARK DELAYSPL //START COOLDOWN
PLON MACRO XIDI,PNT8 //COOL DOWN ZONE
ADVANCE 2.45
BLET &EPROD(7)=&EPROD(7)+1 //COUNT ENGINE IN PROCESS
BLET &PRORATE(5)=&PRORATE(5)+1 //COUNT ENGINE IN PROCESS
BARG MACRO RT5,TOP,&PRORATE(5)
GATE LC SPNT8 //CAPTURE EXIT STOP
LOGIC S SPNT8
BLET PL(CYCLE)=&COOL-MPSDEAYSPL //AWAIT COOLDOWN
TEST G PL(CYCLE),0,*+2
ADVANCE PL(CYCLE) //AWAIT COOLING
LOGIC C SPNT8
BLET PF(PCODE)=FnTRIM //PC=FINAL TRIM
TEST G &TRIM(PFSENGINE),0,*+2
BLET PF(DELRT)=99 //TAG AS BLUEBIRD
BLET PF(CVSEC)=PF(PCODE)*20 //BACKBONE ENTRY
LINK SPNT8,FIFO,PST050
PST050 ENTER (294+PFSPCODE)
BARG4 MACRO PQ,(PFSPCODE-3),TOP,100.0*(S(294+PFSPCODE))/(S(294+PFSPCODE)+
R(294+PFSPCODE))
ENTER PF(CVSEC)
ENTER STRMI
PLON MACRO XIDI,MTRM1
ADVANCE .55 //MERGE ZONE
LEAVE SPNT8
LEAVE STRMI
UNLINK SPNT8,PST050,1
TRANSFER ,TRM030 //RETURN TO BB

PST100 TEST = (294+PFSPCODE),1,TCT120
BLET PF(LCTR)=2
PST110 UNLINK SPNT3,PST020,1
ADVANCE .1
LOOP LCTRSPF,PST110
PST120 TERMINATE

FIN000 TEST NE PF(DELRT),99,BLU000 //BLUEBIRD ENGINE?
BLET 40FLDENGS=40FLDENGS+1
BLET ML(PROD,PFSENGINE,2)=ML(PROD,PFSENGINE,2)+1
BLET ML(PROD,100,2)=ML(PROD,100,2)+1
BLET &TRMENG5=TRMENG5+1
BLET ML(PROD,PFSENGINE,2)=ML(PROD,PFSENGINE,2)+1
BLET ML(PROD,100,2)=ML(PROD,100,2)+1
BLET &EPROD5=EPROD5+1 //COUNT ENGINE IN PROCESS
BLET &INV572(PFSENGINE)=&INV572(PFSENGINE)+1 //COUNT IN
BLET &INV572(100)=&INV572(100)+1 //COUNT IN TOTAL
BLET &INPROC=INPROC+1 //COUNT OUT
LEAVE EWIPQ
WRITE MACRO INP,&INPROC
BARG MACRO IPB,RIGHT,4INPROC
WRITE MACRO IV572,&INV572(100)
BARG MACRO IV3,RIGHT,4INV572(100)
TEST G PL(PLTIME),0,FIN010 //NON-INITIAL LOAD?
* COLLECT TIME BY ENGINE
BLET ML(PROTIME,PFSENGINE,1)=ML(PROTIME,PFSENGINE,1)+MPSLAPTIMSPL
BLET ML(PROTIME,PFSENGINE,2)=ML(PROTIME,PFSENGINE,2)+1
BLET ML(PROTIME,PFSENGINE,3)=ML(PROTIME,PFSENGINE,3)+1,"="
TEST E ML(PROTIME,PFSENGINE,4)=ML(PROTIME,PFSENGINE,4)+1,"="
BLET ML(PROTIME,PFSENGINE,5)=ML(PROTIME,PFSENGINE,5)+1,"="
TEST G MPSLAPTIMSPL,ML(PROTIME,PFSENGINE,4),","=
BLET ML(PROTIME,PFSENGINE,4)=ML(PROTIME,PFSENGINE,4)+1,"="
TEST L MPSLAPTIMSPL,ML(PROTIME,PFSENGINE,5),","=
BLET ML(PROTIME,PFSENGINE,5)=ML(PROTIME,PFSENGINE,5)+1,"="
* COLLECT TIME IN TOTAL
BLET ML(PROTIME,100,1)=ML(PROTIME,100,1)+MPSLAPTIMSPL
BLET ML(PROTIME,100,2)=ML(PROTIME,100,2)+1
BLET ML(PROTIME,100,3)=ML(PROTIME,100,3)+1,"="
TEST E ML(PROTIME,100,4)=ML(PROTIME,100,4)+1,"="
BLET ML(PROTIME,100,5)=ML(PROTIME,100,5)+1,"="
TEST G MPSLAPTIMSPL,ML(PROTIME,100,4),","=
BLET ML(PROTIME,100,4)=ML(PROTIME,100,4)+1,"="
TEST L MPSLAPTIMSPL,ML(PROTIME,100,5),","=
BLET ML(PROTIME,100,5)=ML(PROTIME,100,5)+1,"="
WRITE MACRO SYST,(ML(PROTIME,100.3)/60.0)
* PROCESS COUNT
FIN010 BLET ML(ESYSPRF,1,2)=ML(ESYSPRF,1,2)+1
TEST E ML(ESYSPRF,1,2)+1,"="
BLET ML(ESYSPRF,1,5)=INPROC //MIN
TEST L &INPROC,ML(ESYSPRF,1,5),","=
BLET ML(ESYSPRF,1,5)=INPROC //MIN

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
* FINISH SEQUENCE

**FINISH ORDER**

BLET &FINORD=FINORD+1

BLET ML(SEQVAR,PFSENGINE,1)=ML(SEQVAR,PFSENGINE,1)+VSFINSEQ

BLET ML(SEQVAR,PFSENGINE,2)=ML(SEQVAR,PFSENGINE,2)+1

BLET ML(SEQVAR,PFSENGINE,3)=ML(SEQVAR,PFSENGINE,1)/ML(SEQVAR,PFSENGINE,2)

**TEST E**

BLET ML(SEQVAR,PFSENGINE,4)=VSFINSEQ /MAX

BLET ML(SEQVAR,PFSENGINE,5)=VSFINSEQ /MIN

**TEST G**

BLET ML(SEQVAR,PFSENGINE,4)=VSFINSEQ /MAX

BLET ML(SEQVAR,PFSENGINE,5)=VSFINSEQ /MIN

**TEST L**

BLET ML(SEQVAR,PFSENGINE,4)=VSFINSEQ /MAX

BLET ML(SEQVAR,PFSENGINE,5)=VSFINSEQ /MIN

* FINISH SEQUENCE IN TOTAL

**IN TOTAL**

BLET ML(SEQVAR,100,1)=ML(SEQVAR,100,1)+VSFINSEQ

BLET ML(SEQVAR,100,2)=ML(SEQVAR,100,2)+1

BLET ML(SEQVAR,100,3)=ML(SEQVAR,100,1)/ML(SEQVAR,100,2)

**TEST E**

BLET ML(SEQVAR,100,4)=VSFINSEQ /MAX

BLET ML(SEQVAR,100,5)=VSFINSEQ /MIN

**TEST G**

BLET ML(SEQVAR,100,4)=VSFINSEQ /MAX

BLET ML(SEQVAR,100,5)=VSFINSEQ /MIN

**TEST L**

BLET ML(SEQVAR,100,4)=VSFINSEQ /MAX

BLET ML(SEQVAR,100,5)=VSFINSEQ /MIN

FIN050

**MARK**

LATIMSPL /TIME IN TRUCK GRID

BLET FP(LOC2)=0 /ZERO OUT

SELECT E LOCl,300,PFSTSEQN.XH,FIN055

JOIN PFSL0C1

TEST E GIPFSLOC1),&TRKLD(PFSTSEQN),FIN060

SPLIT 1,SHP000

TRANSFER FIN060

FIN055

SELECT E LOCl,300,0,XH

JOIN PFSL0C1

BLET PFSL0C2=1

QUEUE TGRIDS

FIN060

LINK FINV,FIFO /GO INTO INVENTORY

FIN080

LEAVE TOTALQ

REMOVE PFSL0C1

BLET &INV572(PFSENGINE)=&INV572(PFSENGINE)-1

BLET &INV572(100)=&INV572(100)-1

* WAREHOUSE COUNT-MINIMUM

BLET ML(ESYSPRF,2,2)=ML(ESYSPRF,2,2)+1

**TEST E**

BLET ML(ESYSPRF,2,2)=CH(FINV) /MIN

**TEST L**

BLET ML(ESYSPRF,2,5)=CH(FINV) /MIN

BLET ML(ESYSPRF,3,2)=ML(ESYSPRF,3,2)+1

**TEST E**

BLET ML(ESYSPRF,3,2)=S(TOTALQ) /MIN

**TEST L**

BLET ML(ESYSPRF,3,5)=S(TOTALQ) /MIN

BLET ML(ESYSPRF,2,5)=S(TOTALQ) /MIN

BLET ML(ESYSPRF,3,5)=S(TOTALQ) /MIN

* COLLECT WAREHOUSE TIME BY ENGINE

FIN090

**TEST G**

PL(LATIMSPL),0,FIN095

BLET ML(WHSETIM,PFSENGINE,1)=ML(WHSETIM,PFSENGINE,1)+MPSLAPTIMSPL

BLET ML(WHSETIM,PFSENGINE,2)=ML(WHSETIM,PFSENGINE,2)+1

BLET ML(WHSETIM,PFSENGINE,3)=ML(WHSETIM,PFSENGINE,1)/ML(WHSETIM,PFSENGINE,2)

**TEST G**

BLET ML(WHSETIM,PFSENGINE,4)=MPSLAPTIMSPL /MAX

**TEST E**

BLET ML(WHSETIM,PFSENGINE,5)=MPSLAPTIMSPL /MIN

BLET ML(WHSETIM,PFSENGINE,4)=MPSLAPTIMSPL /MAX

**TEST L**

ML(WHSETIM,PFSENGINE,5)=MPSLAPTIMSPL /MIN

* COLLECT WAREHOUSE TIME IN TOTAL

BLET ML(WHSETIM,100,1)=ML(WHSETIM,100,1)+MPSLAPTIMSPL

BLET ML(WHSETIM,100,2)=ML(WHSETIM,100,2)+1

BLET ML(WHSETIM,100,3)=ML(WHSETIM,100,1)/ML(WHSETIM,100,2)
TEST E  ML(WHSETIM, 100,2), 1, * + 3
BLET ML(WHSETIM, 100, 4) = MPSLAPTIMSPL // MAX
TEST G MPSLAPTIMSPL, ML(WHSETIM, 100, 4), * - 2
BLET ML(WHSETIM, 100, 4) = MPSLAPTIMSPL // MAX
TEST L MPSLAPTIMSPL, ML(WHSETIM, 100, 5), * + 2
BLET ML(WHSETIM, 100, 5) = MPSLAPTIMSPL // MIN

* DAILY SHIPMENTS
FIN095 BLET MH(DSHIPS, PFSENGINE, &SDAY) = MH(DSHIPS, PFSENGINE, &SDAY) + 1
BLET MH(DSHIPS, PFSENGINE, 21) = MH(DSHIPS, PFSENGINE, 21) + 1
BLET MH(DSHIPS, PFSENGINE, 100, &SDAY) = MH(DSHIPS, PFSENGINE, 100, &SDAY) + 1
BLET MH(DSHIPS, PFSENGINE, 100, 21) = MH(DSHIPS, PFSENGINE, 100, 21) + 1
WRITE MACRO IV572, &INV572(100)
BLET MACRO IVB, RIGHT, &INV572(100)
WRITE MACRO SPE, MH(DSHIPS, 100, 21)
BLET MACRO SPB, RIGHT, MH(DSHIPS, 100, 21)
BLET &EPROD(6) = &EPROD(6) + 1 // COUNT ENGINE IN PROCESS
TEST E PF(LOC2), 1, FIN100
DEPART TGRIDS
BLET PF(INDX) = MAX(DSHIPS, PFSSEQNM, 5) // CUSTOMER#
BLET MH(TSHIPS, PFSJNDX, &SDAY) = MH(TSHIPS, PFSJNDX, &SDAY) + 1
BLET MH(TSHIPS, PFSJNDX, 21) = MH(TSHIPS, PFSJNDX, 21) + 1
BLET MH(TSHIPS, PFSJNDX, 100, &SDAY) = MH(TSHIPS, PFSJNDX, 100, &SDAY) + 1
BLET MH(TSHIPS, PFSJNDX, 100, 21) = MH(TSHIPS, PFSJNDX, 100, 21) + 1
BLET &EPROD(6) = &EPROD(6) + 1 // COUNT ENGINE IN PROCESS

* COLLECT GRID TIME BY CUSTOMER
BLET MLGRIDTIM, PFSJNDX, 1) = MLGRIDTIM, PFSJNDX, 1) + MPSLAPTIMSPL
BLET MLGRIDTIM, PFSJNDX, 2) = MLGRIDTIM, PFSJNDX, 2) + MPSLAPTIMSPL
BLET MLGRIDTIM, PFSJNDX, 3) = MLGRIDTIM, PFSJNDX, 3) + MPSLAPTIMSPL
BLET MLGRIDTIM, PFSJNDX, 4) = MLGRIDTIM, PFSJNDX, 4) + MPSLAPTIMSPL
BLET MLGRIDTIM, PFSJNDX, 5) = MLGRIDTIM, PFSJNDX, 5) + MPSLAPTIMSPL
BLET MLGRIDTIM, PFSJNDX, 6) = MLGRIDTIM, PFSJNDX, 6) + MPSLAPTIMSPL

* COLLECT GRID TIME IN TOTAL
BLET MLGRIDTIM, 100, 1) = MLGRIDTIM, 100, 1) + MPSLAPTIMSPL
BLET MLGRIDTIM, 100, 2) = MLGRIDTIM, 100, 2) + MPSLAPTIMSPL
BLET MLGRIDTIM, 100, 3) = MLGRIDTIM, 100, 3) + MPSLAPTIMSPL
BLET MLGRIDTIM, 100, 4) = MLGRIDTIM, 100, 4) + MPSLAPTIMSPL
BLET MLGRIDTIM, 100, 5) = MLGRIDTIM, 100, 5) + MPSLAPTIMSPL
BLET MLGRIDTIM, 100, 6) = MLGRIDTIM, 100, 6) + MPSLAPTIMSPL

FIN100 TERMINATE

* SHIPPING SCHEDULE
SHP000 BLET PF(DELRT) = 0 // STARTING TRUCK
GATE LC DINIT, SHP010 // IS ONE HERE?
SPLIT 1, SIMC90 // YES; CREATE SIMULATION CONTROL
GATE LS DINIT
SHP010 BLET PF(INDX) = 0 // RESET INDEX
MARK LAPTIMSPL
BLET PF(PTR) = 0 // ZERO OUT
BLET &DUM = '572'
TRANSFER SBR, FNMOD, SUBRSPF
BLET PF(CLOC) = SHIPR // SHIPPER LOCATES ENGINES
BLET PL(CYCLE) = &SHPTIM(1)
TRANSFER SBR, PRO00, SUBRSPF // PROCESS TIME
BLET PF(CLOC) = ANALYST // ANALYSIS PRINTS TAGS
BLET PL(CYCLE) = &SHPTIM(2)
TRANSFER SBR, PRO00, SUBRSPF // PROCESS TIME
BLET PF(CLOC) = SHIPR // SHIPPER TAGS ENGINES
BLET PL(CYCLE) = &SHPTIM(3)
TRANSFER SBR, PRO000, SUBRSPF // PROCESS TIME
ENTER DOCKS //YES;OPEN DOCK DOOR?
BLET PF(CLOC)=TRCK572 //TRUCKERS LOAD TRUCK
BLET PL(CYCLE)=&SHPTIM(4)
TRANSFER SBR,PRO000,SUBR&PF //PROCESS TIME
BLET PF(CLOC)=CLERK //TRUCKERS LOAD TRUCK
BLET PL(CYCLE)=&SHPTIM(5)
TRANSFER SBR,PRO000,SUBR&PF //PROCESS TIME
LEAVE DOCKS //TRUCK LEAVES DOCK
UNLINK FINV,FIN080,ALL,TSEQNS&PF,PFSTSEQN
BLET XH(PFS.LOC1)=0

* COLLECT TRUCK LOAD TIME BY CUSTOMER
BLET PF(JNDX)=MX(SHIPS,PFSSEQNM,5) //CUSTOMER
BLET ML(TRLDTIM,PFSJNDX,1)=ML(TRLDTIM,PFSJNDX,1)+MPSLAPTIMSPL
BLET ML(TRLDTIM,PFSJNDX,2)=ML(TRLDTIM,PFSJNDX,2)-1
BLET ML(TRLDTIM,PFSJNDX,3)=ML(TRLDTIM,PFSJNDX,1)/ML(TRLDTIM,PFSJNDX,2)
TEST E ML(TRLDTIM,PFSJNDX,2),1,*=3
BLET ML(TRLDTIM,PFSJNDX,4)=MPSLAPTIMSPL //MAX
BLET ML(TRLDTIM,PFSJNDX,5)=MPSLAPTIMSPL //MIN
TEST G MPSLAPTIMSPL,ML(TRLDTIM,PFSJNDX,4),=*-2
BLET ML(TRLDTIM,PFSJNDX,4)=MPSLAPTIMSPL //MAX
TEST L MPSLAPTIMSPL,ML(TRLDTIM,PFSJNDX,5),=*-2
BLET ML(TRLDTIM,PFSJNDX,5)=MPSLAPTIMSPL //MIN

* COLLECT TRUCK LOAD TIME IN TOTAL
BLET ML(TRLDTIM,100,1)=ML(TRLDTIM,100,1)+MPSLAPTIMSPL
BLET ML(TRLDTIM,100,2)=ML(TRLDTIM,100,2)-1
BLET ML(TRLDTIM,100,3)=ML(TRLDTIM,100,1)/ML(TRLDTIM,100,2)
TEST E ML(TRLDTIM,100,2),1,*=3
BLET ML(TRLDTIM,100,4)=MPSLAPTIMSPL //MAX
BLET ML(TRLDTIM,100,5)=MPSLAPTIMSPL //MIN
TEST G MPSLAPTIMSPL,ML(TRLDTIM,100,4),=*-2
BLET ML(TRLDTIM,100,4)=MPSLAPTIMSPL //MAX
TEST L MPSLAPTIMSPL,ML(TRLDTIM,100,5),=*-2
BLET ML(TRLDTIM,100,5)=MPSLAPTIMSPL //MIN
TERMINATE

* REJECT % SUBROUTINE
*RPTC00 TEST LE PF(PCT),50,RPTC50 //100%
RPTC10 TEST E PFSCRT&FN12,0,RPTC70 //NO;REJECT?
BLET PF(RJCT)=1 //YES;TAG
TRANSFER ,PF(SUBR)+1 //RETURN

RPTC50 TEST NE PF(PCT),100,(PFSSUBR+1) //100%
TEST E PFSCRT82,0,RPTC60 //50% GET REJECT
RPTC55 BLET PF(RJCT)=1 //YES;TAG
TRANSFER ,PF(SUBR)+1 //RETURN
RPTC60 BLET PF(PCT)=PF(PCT)-50 //REDUCE ORIGINAL BY 50%
TRANSFER .RPTC10
RPTC70 TEST G FN13,0,(PFSSUBR+1) //2NDARY REJECT ADD?
TEST E PFSCRT88,0,(PFSSUBR+1) //NO;REJECT?
BLET PF(RJCT)=1 //YES;TAG
TRANSFER ,PF(SUBR)+1 //RETURN

* FIND MODULE # SUBROUTINE
* FNDMOD BLET PF(MOD)=0 //ZERO OUT
FNDMOD BLET PF(MOD)=PF(MOD)-1 //BUMP
TRANSFER &MODID(PFSMOD),&DUM,(PFSSUBR+1) //RETURN IF MATCH

* DOWN TIME LOGIC
*---------------------------
DWT000 TEST NE PF(JNDX),0,DWT100 //ANY DELAY TIME SPECIFIED?
DWT010 ADVANCE &DELAY1(PFSINDX) //TIME UNTIL 1ST DELAY
DWT020 LOGIC S 450+PF(INDEX) //CREATE DELAY STOPPAGE
SCOLOR3 MACRO DOBJ,PFSINDX,'RED'
SCOLOR3 MACRO DOBJ,PFSINDX,'RED'
SCOLOR3 MACRO DOBJ,PFSINDX,'RED'
LOGIC C 450+PF(INDEX) //REMOVE BLOCKAGE

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
ADVANCE &MTBF(PFSINDEX) //MEAN TIME BETWEEN FAILURE
LOOP LCTRSPP,DWT020 //CONTINUE W/ #DELAYS
DWT100 TERMINATE //NUMBER COMPLETE

* DAY DEFINITION AND SIMULATION DURATION *

SIMC00 BLET &SDAY=1 //STARTING DAY
LOGIC D DINIT //RELEASE REST
TRANSFER .SIMC15
SIMC10 BPUTPF &SDAY //INDICATE MODEL STATUS
Simulating Production Day: 
WRITE MACRO DAY, &SDAY
UNLINK FAILS,DWT010, ALL, JNDS, PF, &SDAY //FREE DELAYS
SIMC10 ADVANCE 1440 //NEXT DAY
SPLIT 1,SIMC99 //CREATE TERMINATION PULSE
PRIORITY -1,YIELD //LET IT GET THERE
PRIORITY 0
TEST G NSSIMC10,0,SIMC10
BLET &SDAY= &SDAY-1 //BUMP DAY
TEST LE &SDAY, &NDAYS,SIMC20
TRANSFER .SIMC10 //REPEAT
SIMC20 TERMINATE

* RATE COLLECTION/PLOTTING LOGIC *

PLT000 BLET PF(CLOC)=0
BLET PF(LCTR)=6
PLT010 BLET PL(PFSLCTR)=0
LOOP LCTRSPP,PLT010
BLET PF(LOC)=0
SPLIT 5, PLT020, LOCISPF
PLT020 BLET PF(PLOC)*PF(CLOC)
BLET PF(CLOC)*PF(CLOC)+1
TEST E PF(CLOC),25,PLT030
BLET PF(CLOC)=1
BLET PF(PLOC)=0
PLT030 BLET &NUM= &TOCHAR(PFSLOC)
BLET &NUM=*'||&NUM
TEST NE PF(LOC),1,6, PLT040
PLT040 ADVANCE 0
PLT040 MACRO RTPLT, PFSLOC1, &NUM, PFSLOC, PL(PFSLOC1), PFSLOC, _
&PRORATE(PFSLOC1), &PCLR(PFSLOC1-1)
TRANSFER SBR, FLOW00, SUBRSPPF
PLT050 BLET PF(CLOC)=0
TEST G &PRORATE(PFSLOC1),0. (PFSSUBR+1)
BLET ML(FLOWRT, PFSLOC1,1)+ML(FLOWRT, PFSLOC1,1)*&PRORATE(PFSLOC1)
BLET ML(FLOWRT, PFSLOC1,2)=ML(FLOWRT, PFSLOC1,2)-1
BLET ML(FLOWRT, PFSLOC1,3)=ML(FLOWRT, PFSLOC1,1)/ML(FLOWRT, PFSLOC1,2)
TEST E ML(FLOWRT, PFSLOC1,2),1,*=1
BLET ML(FLOWRT, PFSLOC1,4)*&PRORATE(PFSLOC1) //MAX
BLET ML(FLOWRT, PFSLOC1,5)=&PRORATE(PFSLOC1) //MIN
TEST G &PRORATE(PFSLOC1),ML(FLOWRT, PFSLOC1,4),*+2
BLET ML(FLOWRT, PFSLOC1,4)=&PRORATE(PFSLOC1) //MAX
TEST L &PRORATE(PFSLOC1),ML(FLOWRT, PFSLOC1,5),*=2
BLET ML(FLOWRT, PFSLOC1,5)=&PRORATE(PFSLOC1) //MIN
TRANSFER , (PFSSUBR+1)

* FLOW METER DATA COLLECTION *

FLOW00 TEST G &PRORATE(PFSLOC1),0. (PFSSUBR+1)
BLET ML(FLOWRT, PFSLOC1,1)=ML(FLOWRT, PFSLOC1,1)+&PRORATE(PFSLOC1)
BLET ML(FLOWRT, PFSLOC1,2)=ML(FLOWRT, PFSLOC1,2)-1
BLET ML(FLOWRT, PFSLOC1,3)=ML(FLOWRT, PFSLOC1,1)/ML(FLOWRT, PFSLOC1,2)
TEST E ML(FLOWRT, PFSLOC1,2),1,*=1
BLET ML(FLOWRT, PFSLOC1,4)*&PRORATE(PFSLOC1) //MAX
BLET ML(FLOWRT, PFSLOC1,5)=&PRORATE(PFSLOC1) //MIN
TEST G &PRORATE(PFSLOC1),ML(FLOWRT, PFSLOC1,4),*+2
BLET ML(FLOWRT, PFSLOC1,4)=&PRORATE(PFSLOC1) //MAX
TEST L &PRORATE(PFSLOC1),ML(FLOWRT, PFSLOC1,5),*=2
BLET ML(FLOWRT, PFSLOC1,5)=&PRORATE(PFSLOC1) //MIN
TRANSFER , (PFSSUBR+1)
* CRITICAL QUEUE DATA COLLECTION
*
KEYQ0 BLET ML(\text{KEYQUE}, \text{PFSLOC1}, 1) = ML(\text{KEYQUE}, \text{PFSLOC1}, 1) + FN(\text{PROCQ})

BLET ML(\text{KEYQUE}, \text{PFSLOC1}, 2) = ML(\text{KEYQUE}, \text{PFSLOC1}, 2) + 1

TEST E ML(\text{KEYQUE}, \text{PFSLOC1}, 2, 1, */=3)

BLET ML(\text{KEYQUE}, \text{PFSLOC1}, 4) = FN(\text{PROCQ}) //MAX

BLET ML(\text{KEYQUE}, \text{PFSLOC1}, 5) = FN(\text{PROCQ}) //MIN

TRANSFER , (\text{PFSSUBR}+1)

SIMP90 SPLIT 1, SIMCOO  //DONE INITIALIZING

SIMP99 TERMINATE 1

START 2, NP

RESET

LET $\text{EPROD}(1) = 0$

LET $\text{EPROD}(2) = 0$

LET $\text{EPROD}(3) = 0$

LET $\text{EPROD}(4) = 0$

LET $\text{EPROD}(5) = 0$

LET $\text{EPROD}(6) = 0$

LET $\text{EPROD}(7) = 0$

LET $\text{EPROD}(8) = 0$

LET $\text{PRORATE}(1) = 0$

LET $\text{PRORATE}(2) = 0$

LET $\text{PRORATE}(3) = 0$

LET $\text{PRORATE}(4) = 0$

LET $\text{PRORATE}(5) = 0$

LET $\text{PRORATE}(6) = 0$

LET $\text{HJCOTIM} = 0$

INITIAL ML$\text{SPROD}(1-100, 2-9), 0$

INITIAL ML$\text{SHIPS}(1-100, 1-21), 0$

START &RUNDAYS

PUTPIC &SDAY

Simulation Completed:

* REPORT

* OUTPUT

PUTPIC FILE=OUT, LINES=5, CURDATE

ENGINE WORKS TEST, TRIM, PAINT & SHIP SIMULATION

INPUT CONDITIONS:

PUTPIC FILE=OUT, LINES=10, (&TESTID, &TESTDSR, _
&PRODVOL(1), &PRODVOL(2), &PRODVOL(3), _
&LBCTMAIN, &HRPRTIM, &LRPRTIM, &LRPRRJ+100.0, _
&CRPRTIM, &CRPRRJ+100.0, &DOCK)

TEST: *

SCENARIO: *

AVG. LINE RATE-1ST: **** ENGINES/SHIFT

AVG. LINE RATE-2ND: **** ENGINES/SHIFT

AVG. LINE RATE-3RD: **** ENGINES/SHIFT

# LOAD BARS - MAIN:

HEAVY REPAIR:

LIGHT REPAIR:

CELL DELAY:

# EFFECTIVE DOCKS:

PUTPIC FILE=OUT, LINES=8, (&SDAY)

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
RESULTS AFTER: ** SIMULATION DAYS

ENGINE PRODUCTION SUMMARY:

| PUTPIC FILE=OUT, LINES=9, &EPROD(1), FLT(&EPROD(1)/&SDAY), - |
| &EPROD(1), FLT(&EPROD(1)/&SDAY), &J=3,5, - |
| &EPROD(7), FLT(&EPROD(7)/&SDAY), - |
| MH(TSHIPS,100,21), FLT(MH(TSHIPS,100,21))/&SDAY, - |
| FLT(&SDAY), MH(TSHIPS,100,21), FLT(MH(TSHIPS,100,21))/&SDAY, - |
| FLT(&SDAY), MH(TSHIPS,100,21), FLT(MH(TSHIPS,100,21))/&SDAY, - |
| TOTAL AVG./DAY |
| J-HOOK PRODUCTION: | ----- | ----- |
| TEST PRODUCTION: | **** | **** |
| CUSTOM TRIM PRODUCTION: | **** | **** |
| FINAL TRIM PRODUCTION: | **** | **** |
| PAINT PRODUCTION: | **** | **** |
| ENGINE SHIPPED: | **** | **** |
| TRUCKS SHIPPED: | **** | **** |

FLOW RATE BY DEPARTMENT:

<table>
<thead>
<tr>
<th>DEPARTMENT</th>
<th>TOTAL PRODUCED</th>
<th>*ENGINES IN PROCESS/ J-HOOK TO 572:</th>
<th>*ENGINES IN 572 (TRUCK GRIDS):</th>
<th>*TRUCK GRIDS:</th>
<th>TOTAL ENGINES AFTER J-HOOK:</th>
<th>TRUCK DOCK USAGE SUMMARY:</th>
</tr>
</thead>
</table>

PUTPIC FILE=OUT, LINES=4, ((ML(PROTIME,100,&W)/1440.0, &W=3,5), - |
| (ML(WHSETIM,100,&W)/1440.0, &W=3,5), (ML(TRKLDTIM,100,&W)/1440.0, - |
| &W=3,5)) |
| PROCESS TIME IN DAYS/ J-HOOK TO 572: | **** | **** | **** |
| WAREHOUSE TIME IN DAYS: | **** | **** | **** |
| TRUCK LOAD TIME IN DAYS: | **** | **** | **** |

PUTPIC FILE=OUT, LINES=3, (ML(SEQVAR,100,&W), &W=3,5)
J-Hook Changeovers

<table>
<thead>
<tr>
<th>TOTAL</th>
<th>AVG./DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td># Changeovers:</td>
<td>****</td>
</tr>
<tr>
<td>Changeover Time (Hours):</td>
<td>****</td>
</tr>
<tr>
<td>% Changeover:</td>
<td>****</td>
</tr>
</tbody>
</table>

Hourly Flow Meter Summary (Units/Hour)

<table>
<thead>
<tr>
<th>Area</th>
<th>AVG.</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO</td>
<td>&amp;I=1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IF</td>
<td>&amp;I=1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>&amp;DUM='JHOOK'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSEIF</td>
<td>&amp;I=2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>&amp;DUM='TEST'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSEIF</td>
<td>&amp;I=3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>&amp;DUM='CUSTOM TRIM'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSEIF</td>
<td>&amp;I=4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>&amp;DUM='FINAL TRIM'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>&amp;DUM='PAINT'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENDIF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUTPIC</td>
<td>FILE=OUT, &amp;DUM, (ML(FLOWRT, &amp;I, &amp;J), &amp;J=3, 5)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Critical Queue Summary

<table>
<thead>
<tr>
<th>Area</th>
<th>AVG.</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO</td>
<td>&amp;I=1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IF</td>
<td>&amp;I=1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>&amp;DUM='EMPTY'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSEIF</td>
<td>&amp;I=2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>&amp;DUM='ATTIC'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSEIF</td>
<td>&amp;I=3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>&amp;DUM='TEST LOOP'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSEIF</td>
<td>&amp;I=4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>&amp;DUM='CUSTOM TRIM'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSEIF</td>
<td>&amp;I=5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>&amp;DUM='FINAL TRIM'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>&amp;DUM='PAINT'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENDIF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUTPIC</td>
<td>FILE=OUT, &amp;DUM, (ML(KEYQUE, &amp;I, &amp;J), &amp;J=3, 5)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Engine Production Detail:

Daily Engines Shipped:

<table>
<thead>
<tr>
<th>Engine</th>
<th>Production Days:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5 6 7 8 9 10</td>
</tr>
<tr>
<td>DO</td>
<td>&amp;I=1.99</td>
</tr>
<tr>
<td>IF</td>
<td>MH(DSHIPS, &amp;I, 21) &lt; 0</td>
</tr>
<tr>
<td>PUTPIC</td>
<td>FILE=OUT, &amp;PARTNO( &amp;I ) , (MH(DSHIPS, &amp;I, &amp;J), &amp;J=1, 10), _</td>
</tr>
<tr>
<td>ENDIF</td>
<td></td>
</tr>
<tr>
<td>ENDDO</td>
<td></td>
</tr>
</tbody>
</table>

Total |

Daily Truck Shipment by Customer:
CUSTOMER

DO &I=1,99
IF MH(TSHIPS,I,21)>0
PUTPIC FILE=OUT,CUSTID(&I),(MH(TSHIPS,I,10),._
MH(TSHIPS,I,21)
**********
ENDIF
ENDDO
PUTPIC FILE=OUT,LINES=8,(MH(TSHIPS,100,10),._
MH(TSHIPS,100,21)

TOTAL

****  ****  ****  ****  ****  ****  ****  ****  ****  ****

ENGINE PROCESS DETAIL:

PROCESS TIME BETWEEN J-HOOK & 572 (IN HOURS):
ENGINE # COMPLETE AVG. MAX. MIN.

DO &I=1,99
IF ML(PROTIME,I,1)>0
PUTPIC FILE=OUT,PARTNO(&I),ML(PROTIME,I,2),._
(ML(PROTIME,I,1)/60.0,4J=1,5)
**********
ENDIF
ENDDO
PUTPIC FILE=OUT,LINES=6,ML(PROTIME,100,2),._
(ML(PROTIME,100,1)/60.0,4J=1,5)

TOTAL:

****  ****  ****  ****  ****  ****  ****  ****  ****  ****

WAREHOUSE TIME (IN HOURS):
ENGINE # COMPLETE AVG. MAX. MIN.

DO &I=1,99
IF ML(WHSETIM,I,1)>0
PUTPIC FILE=OUT,PARTNO(&I),ML(WHSETIM,I,2),._
(ML(WHSETIM,I,1)/60.0,4J=1,5)
**********
ENDIF
ENDDO
PUTPIC FILE=OUT,LINES=6,ML(WHSETIM,100,2),._
(ML(WHSETIM,100,1)/60.0,4J=1,5)

TOTAL:

****  ****  ****  ****  ****  ****  ****  ****  ****  ****

TRUCK GRID TIME (AWAITING SHIPMENT) IN HOURS:
CUSTOMER # COMPLETE AVG. MAX. MIN.

DO &I=1,49
IF ML(GRIDTIM,I,1)>0
PUTPIC FILE=OUT,CUSTID(&I),ML(GRIDTIM,I,2),._
(ML(GRIDTIM,I,1)/60.0,4J=1,5)
**********
ENDIF
ENDDO
PUTPIC FILE=OUT,LINES=6,ML(GRIDTIM,100,2),._
(ML(GRIDTIM,100,1)/60.0,4J=1,5)

TOTAL:

****  ****  ****  ****  ****  ****  ****  ****  ****  ****

TRUCK LOAD TIME IN HOURS:
CUSTOMER # COMPLETE AVG. MAX. MIN.

DO &I=1,49
IF ML(TRKLDTIM,I,1)>0
PUTPIC FILE=OUT,CUSTID(&I),ML(TRKLDTIM,I,2),._
(ML(TRKLDTIM,I,1)/60.0,4J=1,5)
**FINISH SEQUENCE VARIANCE:**

<table>
<thead>
<tr>
<th>ENGINE</th>
<th># COMPLETE</th>
<th>AVG.</th>
<th>MAX.</th>
<th>MIN.</th>
</tr>
</thead>
</table>

**DO**

**ENDDO**

**PUTPIC**

**TOTAL:**

**FINISH SEQUENCE VARIANCE:**

**ENGINE**  | # COMPLETE | AVG. | MAX. | MIN. |
|------------|------------|------|------|------|

**DO**

**ENDIF**

**ENDDO**

**PUTPIC**

**TOTAL:**

**TECHNICIAN PERFORMANCE BY DEPARTMENT**

**DEPT: 568**

**OPERATING DAYS/WEEK:**

**DEPT:**

**OPERATING DAYS/WEEK:**

**TECHNICIAN PERFORMANCE 3Y DEPARTMENT**

**DEPT: 569**

**OPERATING DAYS/WEEK:**

**DEPT:**

**OPERATING DAYS/WEEK:**

**TECHNICIAN PERFORMANCE 3Y DEPARTMENT**

**DEPT: 570**

**OPERATING DAYS/WEEK:**

**DEPT:**

**OPERATING DAYS/WEEK:**

**TECHNICIAN PERFORMANCE 3Y DEPARTMENT**

**DEPT: 571**

**OPERATING DAYS/WEEK:**
### DEPT: 570 ENGINES

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIF</th>
<th># ENGINES PROCESSED</th>
<th>AVG. TIME/ENGINE</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO</td>
<td>&amp;I=301,400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&amp;K=KI-300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IF</td>
<td>MX(TCHASN,&amp;K,1)=5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUTPIC</td>
<td>FILE=OUT,&amp;TCHNM(&amp;K),MX(TCHASN,&amp;K,2),FC(&amp;I),FT(&amp;I),_</td>
<td>FRV(&amp;I)/10.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>*****</td>
<td>***</td>
<td>%</td>
</tr>
<tr>
<td>ENDF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENDDO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUTPIC</td>
<td>FILE=OUT,LINES=6,&amp;WDAYS(6)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### DEPT: 570 PAINT

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIF</th>
<th># TRUCKS PROCESSED</th>
<th>AVG. TIME/TRUCK</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO</td>
<td>&amp;I=301,400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&amp;K=KI-300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IF</td>
<td>MX(TCHASN,&amp;K,1)=6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUTPIC</td>
<td>FILE=OUT,&amp;TCHNM(&amp;K),MX(TCHASN,&amp;K,2),FC(&amp;I),FT(&amp;I),_</td>
<td>FRV(&amp;I)/10.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>*****</td>
<td>***</td>
<td>%</td>
</tr>
<tr>
<td>ENDF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENDDO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUTPIC</td>
<td>FILE=OUT,LINES=6,&amp;WDAYS(6)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Test Summary

```
PUTPIC FILE=TSUM,&TESTID,&TESTIDSCR,CURDATE,FLT(&EPROD(1)/&SDAY),_
(FLT(&EPROD(j)/&SDAY),&J=3,5),FLT(&EPROD(7)/&SDAY),_
FLT(MH(DSHIPS,100,2))/FLT(&SDAY),SA(EWIPQ),SM(EWIPQ),_
CA(FINV),CM(FINV),SA(TOTALQ),SM(TOTALQ),_
(ML(PROTIME,100,&J)/1440.0,&J=3,4),_
(ML(SEQUAR,100,&J),&J=3,5)
```

CLOSE TSUM

END
APPENDIX C

Snapshot of Animated Simulation Run