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

Ahmad Nadeem Choudhry

University of Northern Iowa
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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

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December 2000

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

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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This research was an extension of a previous unpublished study, which investigated the PP&C methods being used at a midwestern manufacturer of agricultural equipment (MMAE).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.

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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.

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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.
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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,
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). Lambrechts 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
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.

- **Genetic algorithm (GA)**: Holland (1992) defines genetic algorithm as "a probabilistically guided search method, developed originally in the 1970s as a computer science tool to improve programming structures and performance" (pp. 66-72). Chambers (1991) defines it as a "problem solving method that uses genetics as its model of problem solving" (p. 9).

- **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)

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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).](image)
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

Time-Phased MRP Requirements Processing

<table>
<thead>
<tr>
<th>Part A</th>
<th>Week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Gross requirements</td>
<td>120</td>
</tr>
<tr>
<td>Schedule receipts</td>
<td></td>
</tr>
<tr>
<td>Projected available balance</td>
<td>400</td>
</tr>
<tr>
<td>Planned order releases</td>
<td></td>
</tr>
</tbody>
</table>

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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

<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.

![Crossover operation](image)

Parent 1: 1 0 1 1 1 1 1 0 0
Parent 2: 0 1 0 0 0 0
Child 1: 1 0 1 1 0 0
Child 2: 0 1 0 0 1 1

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 build 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

YES

Eliminate the frozen order from the file

B

C
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.
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
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 useable 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.
Figure 13. Format orders with formulas visible in the cells.
Figure 14. Sort orders.
<table>
<thead>
<tr>
<th>Factory</th>
<th>Part N</th>
<th>Model</th>
<th>Target Build</th>
</tr>
</thead>
<tbody>
<tr>
<td>D10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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>
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<th>MODEL</th>
<th>DUE DATE</th>
<th>UNIQUE #</th>
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<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>6081HH010</td>
<td>11/05/99</td>
<td>RG2878711/05/996</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>2</td>
<td>NON</td>
<td>1</td>
<td>3.133</td>
</tr>
<tr>
<td>RG23812</td>
<td>2</td>
<td>NON</td>
<td>1</td>
<td>3.167</td>
</tr>
<tr>
<td>RG23878</td>
<td>3</td>
<td>PAINT</td>
<td>5</td>
<td>3.4</td>
</tr>
<tr>
<td>RG23879</td>
<td>3</td>
<td>PAINT</td>
<td>6</td>
<td>3.633</td>
</tr>
<tr>
<td>RG23880</td>
<td>3</td>
<td>PAINT</td>
<td>6</td>
<td>3.7</td>
</tr>
<tr>
<td>RG24703</td>
<td>2</td>
<td>NON</td>
<td>1</td>
<td>3.7</td>
</tr>
<tr>
<td>RG24972</td>
<td>2</td>
<td>NON</td>
<td>1</td>
<td>3.85</td>
</tr>
<tr>
<td>RG26999</td>
<td>2</td>
<td>NON</td>
<td>1</td>
<td>3.85</td>
</tr>
<tr>
<td>RG27003</td>
<td>2</td>
<td>NON</td>
<td>1</td>
<td>3.267</td>
</tr>
<tr>
<td>RG29286</td>
<td>2</td>
<td>NON</td>
<td>2</td>
<td>4.033</td>
</tr>
<tr>
<td>RG29288</td>
<td>2</td>
<td>NON</td>
<td>2</td>
<td>2.65</td>
</tr>
<tr>
<td>RG27004</td>
<td>2</td>
<td>NON</td>
<td>1</td>
<td>3.5</td>
</tr>
<tr>
<td>RG27009</td>
<td>2</td>
<td>PAINT</td>
<td>1</td>
<td>2.733</td>
</tr>
<tr>
<td>RG27019</td>
<td>2</td>
<td>NON</td>
<td>1</td>
<td>2.733</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 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

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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.

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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 MMAE'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 3

**Line-up Dates and Test Numbers**

<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>
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<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>
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<td>10/12/1999</td>
<td>48</td>
<td>12/14/1999</td>
<td>81</td>
</tr>
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<td>8/11/1999</td>
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<td>10/13/1999</td>
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<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>
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<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>
<tr>
<td>9/14/1999</td>
<td>34</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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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>
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</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>

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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

<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>Paint</td>
<td>42.00</td>
<td>8.42</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

<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>Paint</td>
<td>43.80</td>
<td>7.75</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>42.25</strong></td>
<td><strong>3.95</strong></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>
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>

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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>

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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


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. @ 5% REJECT RATE
CELL DELAY: 5.0 MINS. @ 10% DELAY RATE
# EFFECTIVE DOCKS: 3

RESULTS AFTER: 1 SIMULATION DAYS

ENGINE PRODUCTION SUMMARY:

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

ENGINE PROCESS SUMMARY:

<table>
<thead>
<tr>
<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>
</tr>
<tr>
<td># ENGINES IN 572 (TRUCK GRIDS):</td>
<td>67.8</td>
<td>118</td>
<td>11</td>
</tr>
<tr>
<td># TRUCK GRIDS:</td>
<td>5.7</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>TOTAL ENGINES AFTER J-HOOK:</td>
<td>121.4</td>
<td>173</td>
<td>83</td>
</tr>
<tr>
<td>TRUCK DOCK USAGE SUMMARY:</td>
<td>0.3</td>
<td>3</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>
</tr>
<tr>
<td>WAREHOUSE TIME IN DAYS:</td>
<td>0.4</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>TRUCK LOAD TIME IN DAYS:</td>
<td>0.2</td>
<td>0.6</td>
<td>0.0</td>
</tr>
<tr>
<td>ENGINE FINISH SEQUENCE VARIATION:</td>
<td>0.4</td>
<td>52</td>
<td>-70</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></th>
<th>TOTAL</th>
<th>AVG./DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td># Changeovers</td>
<td>4</td>
<td>4.0</td>
</tr>
<tr>
<td>Changeover Time (Hours)</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>% Changeover</td>
<td>3.8%</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>
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### Engine Production Detail

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**Daily Truck Shipment by Customer:**

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ENGINE PROCESS DETAIL:

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WAREHOUSE TIME (IN HOURS):

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**TOTAL:** 197 10.3 23.0 1.1

### TRUCK GRID TIME (AWAITING SHIPMENT) IN HOURS:

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**TOTAL:** 17 8.8 23.0 1.5

### TRUCK LOAD TIME IN HOURS:

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**TOTAL:** 17 5.3 14.5 1.1

### FINISH SEQUENCE VARIANCE:

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**TOTAL:** 292 0.4 52 -70

### TECHNICIAN PERFORMANCE BY DEPARTMENT

**DEPT:** 568
**OPERATING DAYS/WEEK:** 5

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<th>AVG. TIME/</th>
<th>% ULT.</th>
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DEPT: 569
OPERATING DAYS/WEEK: 5

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<td>0.0%</td>
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<td>0.0%</td>
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<td>0.0%</td>
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<tr>
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DEPT: 570
OPERATING DAYS/WEEK: 5

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<tr>
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<tr>
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DEPT: 571
OPERATING DAYS/WEEK: 5

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### DEPT: 572
**OPERATING DAYS/WEEK: 5**

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<th># TRUCKS PROCESSED</th>
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<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>
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<td>5</td>
<td>20.0</td>
<td>22.7 %</td>
</tr>
<tr>
<td>TRUCKER3</td>
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<td>4</td>
<td>18.7</td>
<td>17.0 %</td>
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<tr>
<td>CLERK</td>
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<td>11</td>
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### DEPT: 570 PAINT
**OPERATING DAYS/WEEK: 5**

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<th>% ULT.</th>
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<tbody>
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<tr>
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<td>46</td>
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</table>
Simulation Output (Experimental Condition)
SCHEDULING AND SEQUENCING MODEL SIMULATION  
EXPERIMENTAL 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. @ 5% REJECT RATE
CELL DELAY: 5.0 MINS. @ 10% 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>106</td>
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</tr>
<tr>
<td>TEST PRODUCTION</td>
<td>111</td>
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</tr>
<tr>
<td>CUSTOM TRIM PRODUCTION</td>
<td>68</td>
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</tr>
<tr>
<td>FINAL TRIM PRODUCTION</td>
<td>111</td>
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<tr>
<td>PAINT PRODUCTION</td>
<td>72</td>
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ENGINE PROCESS SUMMARY:

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<th>AVG.</th>
<th>MAX.</th>
<th>MIN.</th>
<th>CURRENT</th>
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</thead>
<tbody>
<tr>
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<td>49.6</td>
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<td>30</td>
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<tr>
<td># ENGINES IN 572 (TRUCK GRIDS):</td>
<td>54.3</td>
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<tr>
<td># TRUCK GRIDS:</td>
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<td>15</td>
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<td>10</td>
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<tr>
<td>TOTAL ENGINES AFTER J-HOOK:</td>
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<td>150</td>
<td>86</td>
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<tr>
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FLOW RATE BY DEPARTMENT:

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<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>
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<td>440</td>
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</table>
# J-Hook Changeovers

- **Total Changeovers:** 7
- **Changeover Time (Hours):** 0.3
- **% Changeover:** 6.6%

## Hourly Flow Meter Summary (Units/Hour)

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<th>Avg.</th>
<th>Max.</th>
<th>Min.</th>
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<tr>
<td>Final Trim</td>
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## Critical Queue Summary

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## Engine Production Detail:

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</table>

### Daily Truck Shipment by Customer:

#### Production Days:

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<table>
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ENGINE PROCESS DETAIL:

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WAREHOUSE TIME (IN HOURS):

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<th>MIN.</th>
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<td>min.</td>
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<td>------------</td>
<td>------</td>
<td>------</td>
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<td>14.6</td>
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**truck grid time (awaiting shipment) in hours:**

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<th>avg.</th>
<th>max.</th>
<th>min.</th>
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</thead>
<tbody>
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<td>OEM</td>
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<td>20.6</td>
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**truck load time in hours:**

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<th>customer</th>
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<th>max.</th>
<th>min.</th>
</tr>
</thead>
<tbody>
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<td>6.8</td>
<td>16.8</td>
<td>1.1</td>
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<td>Davenport</td>
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<td>14.6</td>
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</tr>
<tr>
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<td>12.3</td>
<td>1.1</td>
</tr>
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<td>16.6</td>
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<td><strong>16.8</strong></td>
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**finish sequence variance:**

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<th>min.</th>
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**technician performance by department**

**dept:** 568

**operating days/week:** 5

**technician shift processed engine % ult.**
### DEPT: 569
**OPERATING DAYS/WEEK: 5**

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<th>Shift</th>
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<td>34.6%</td>
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<td>31.7%</td>
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<td>0.0%</td>
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### DEPT: 570
**OPERATING DAYS/WEEK: 5**

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### DEPT: 571
**OPERATING DAYS/WEEK: 5**

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<tr>
<td>FTRIM1 2</td>
<td>62</td>
<td>5.5</td>
<td>58.1 %</td>
<td></td>
</tr>
<tr>
<td>FTRIM2 2</td>
<td>154</td>
<td>1.6</td>
<td>41.5 %</td>
<td></td>
</tr>
<tr>
<td>FTRIM3 2</td>
<td>196</td>
<td>1.5</td>
<td>50.8 %</td>
<td></td>
</tr>
<tr>
<td>FTRIM4 2</td>
<td>148</td>
<td>1.9</td>
<td>48.8 %</td>
<td></td>
</tr>
<tr>
<td>FTRIM5 2</td>
<td>153</td>
<td>1.7</td>
<td>43.4 %</td>
<td></td>
</tr>
<tr>
<td>FTRIM6 2</td>
<td>155</td>
<td>1.9</td>
<td>49.2 %</td>
<td></td>
</tr>
<tr>
<td>FTRIM7 2</td>
<td>157</td>
<td>1.6</td>
<td>42.9 %</td>
<td></td>
</tr>
<tr>
<td>FTRIM8 2</td>
<td>148</td>
<td>1.8</td>
<td>44.5 %</td>
<td></td>
</tr>
<tr>
<td>FTRIM9 2</td>
<td>103</td>
<td>2.1</td>
<td>36.4 %</td>
<td></td>
</tr>
</tbody>
</table>

**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>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: 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>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>
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
BUPTPIC FILE=ATF,(#A,#B)
Set C* Color *
ENDMACRO
*
INTEGER &I,&J,&K,&L,&M,&N,&CDOWN(18),&MAX,&CHOK,&PRVENG
INTEGER &KEYCNYT,&EFAM(20)
REAL &R.,&S.,&T.,&DAY.,&CONVS.,&JHKO.,&PRORATE(6),&JHKCOTIM
REAL &MTBF(20),&DTIM(20),&DELAY(20)
CHAR*12 &PRINNO(100),&ENG.,&CLR(8),&ECLR(100),&NULL
VCHAR*12 &PRVUS.,&PCLR(6),&NUM.,&IT0CHAR(50)
*
---------------------------------------------------------------------
*
* Define job attributes (fullword)
*
ENGINE EQU 1,PF //ENGINE ID
DELT 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
SEQNM EQU 6,PF //ASSEMBLY SEQUENCE #
SUBR EQU 7,PF //SUBROUTINE PARAMETER
PTR EQU 8,PF //POINTER PARAMETER
CTR EQU 9,PF //COUNTER PARAM.
PLOC EQU 10,PF //PREVIOUS location
CLOC EQU 11,PF //CURRENT location
OPNUM EQU 12,PF //OPERATION #
INDEX EQU 13,PF //ULT. INDEX
JINDX EQU 14,PF //ULT. INDEX
SHIFT EQU 15,PF //TECHNICIAN SHIFT
PCT EQU 16,PF //WORKING PCT.
RJCT EQU 17,PF //REJECT INDICATOR (0=NO;1=YES)
SEQN 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
CMPLT EQU 6,PL //COMPLETION ESTIMATE

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**File Variables.**

- VCHAR*8 &TESTID  Test ID.
- VCHAR*80 &TESTDESC  Test description.
- REAL &PRODVOl(3)  Daily production volume.
- INTEGER &RUNDAYS  # of days to run.
- INTEGER &LBCTMAIN  Load bar count in main conveyor.
- INTEGER &LBCTPNT  Load bar count in paint.
- REAL &TXMRTVEN  Time in paint oven (min).

**Data Declarations**

- INTEGER &SHIFTN0, &STAOPMIN, &STAOPMID, &STAOPMAX, &DAYNO
- VCHAR*100 &STRING1
- INTEGER &OFLDENGS
- INTEGER &FTRMENGs
- INTEGER &BBMRG(40)

**CUSTOM TRIM STORAGES: 140-159**

- CTRMQ EQU 140.S.L  //TRIM STATION
- CTLINE EQU 141(9).S.L  //TRIM LINE
- SSTG0 EQU 155.S.L.C  //STAGING ZONE
- STRMI 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
- TFLINE EQU 152.S

```
STORAGE S140.17/S141-148.1/S149.7/S(SSTG0).2
STORAGE S(TCTLINE).5/S(TFLINE).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  //BACKBONE SWITCH

```
STORAGE S(FTRMQ).12
STORAGE S161-S169.1
```

**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

```
```

**569 Repair Storages: 250-259**

- REPRQ EQU 250.S.L  //REPAIR QUEUE
- ERRPRQ EQU 259.S  //EXIT REPAIR

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STORAGE S(REPRQ),4/S(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),14/270.1 //LEAK TEST QUEUE
STORAGE S272-S276.1/271.3 //568 TRIM LINE

* Power & Free Storages: 280-290

SPF1 EQU 281.S.L
SPF2 EQU 282.S
SPL EQU 283.S
SPO EQU 284.S,F

STORAGE S(SPF2),9/S(SPL),1/S(SPO),5

* Gather statistics, traffic control Storages: 290-

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

STORAGE S200.1

* TRANSIT COUNTS STORAGE 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
BACKBCNT EQU 305,S,L,C //BACKBONE TRANSIT LIMIT
BLUEBQ 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.
CELL5W EQU 31(6),L.S
RTORKQ EQU 37.S.C.L //RETOURQUE QUEUE
RTORK1 EQU 38.S.L //RETOURQUE STA 1
RTORK2 EQU 39,S.L,C //RETOURQUE STA 2
RTORQ EQU 40.S.L //RETOURQUE QUEUE
BACKUP EQU 400,S
RECR1L EQU 401,S.L //569 RECIRC IN
RECR2L EQU 402,S.L,C //569 RECIRC
RECR10 EQU 403.S.L //569 EXIT
SPIN1 EQU 404.L //INDICATES RC 1 SEARCHING
RCCAL1 EQU 404.C //CALL CHAIN FOR RC1
RECR2L EQU 405.S.L //570 RECIRC IN
RECR2M EQU 406,S.L,C //570 RECIRC MIDDLE
RECR2O EQU 407,S.L //570 EXIT
RECR2 EQU 408,S //TOTAL RECIRC LOOP
SPIN2 EQU 409.L //INDICATES RC 2 SEARCHING
RCCAL2 EQU 410.C //RECIRC #2 CALL CHAIN
FAILR EQU 450.C //HOLD FAILURE COUNT
DLAYSW EQU 451(L20),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(RECRI0).1/S(RECRI).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(18).F ASSOC. CELL RUN TIME

CSPED EQU 1.XL //CONV. SPEED

* PROCESS CODES & GROUPS

RCRQ1 SYN 1 //REIRCULATE
CLTEST SYN 2 //TEST CELL
RTORQ 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
GLTEST EQU 2.G
GRTORQ EQU 3.G
GAUDIT EQU 4.G
GOFFLD EQU 5.G
GREPAIRS EQU 6.G
GCSTTRIM EQU 7.G
GFNTRIM EQU 8.G
GPNTRIM EQU 9.G
GBBTRIM EQU 10.G
GFNTRBB EQU 11.G
GFNTRPT EQU 12.G
GPNTRBB 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

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Infile 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 'DWNTIM.DAT' //Downtime Scenarios
ATF FILEDEF 'TTPS1.ATF' //ttps Trace File
OUT FILEDEF 'OUTPUT.DAT' //Output Report
TSUM FILEDEF 'TESTSUM.DAT'.APPEND //ACCUMULATION TEST SUMMARY

INITIALIZATION

INITIAL XLSCSPEED, 60.0  /\ CONV. SPEED
INITIAL MLCSSECT(1,1), .34/MLCSSECT(2,1), .54
INITIAL MLCSSECT(3,1), 1.75/MLCSSECT(4,1), .14
INITIAL MLCSSECT(5,1), .32/MLCSSECT(6,1), .75
INITIAL MLCSSECT(7,1), .36/MLCSSECT(8,1), 1.59
INITIAL MLCSSECT(9,1), .39/MLCSSECT(10,1), 1.14
INITIAL MLCSSECT(11,1), .90/MLCSSECT(12,1), .30
INITIAL MLCSSECT(13,1), .26/MLCSSECT(14,1), .91
INITIAL MLCSSECT(15,1), .27/MLCSSECT(16,1), 3.02
INITIAL MLCSSECT(17,1), .35/MLCSSECT(18,1), 11.22
INITIAL MLCSSECT(19,1), 1.04
INITIAL MLCSSECT(31,1), .26/MLCSSECT(32,1), .84
INITIAL MLCSSECT(33,1), .18/MLCSSECT(34,1), .28
INITIAL MLCSSECT(39,1), .50

INITIAL MLCSSECT(1,11), .12/MLCSSECT(2,11), .33
INITIAL MLCSSECT(3,11), .35/MLCSSECT(4,11), .12
INITIAL MLCSSECT(9,11), .07
INITIAL MLCSSECT(11,11), .08/MLCSSECT(12,11), .07
INITIAL MLCSSECT(13,11), .12
INITIAL MLCSSECT(15,11), .15
INITIAL MLCSSECT(17,11), .14
INITIAL MLCSSECT(19,11), .14
INITIAL MLCSSECT(32,11), .13/MLCSSECT(33,11), .13
INITIAL MLCSSECT(38,11), .42/MLCSSECT(39,11), .21

INITIAL MLCSSECT(1,12), .33/MLCSSECT(2,12), .14
INITIAL MLCSSECT(3,12), .22/MLCSSECT(4,12), .12
INITIAL MLCSSECT(9,12), .08
INITIAL MLCSSECT(11,12), .08/MLCSSECT(12,12), .15
INITIAL MLCSSECT(13,12), .13
INITIAL MLCSSECT(15,12), .22
INITIAL MLCSSECT(17,12), .14
INITIAL MLCSSECT(32,12), .15/MLCSSECT(33,12), .14

INITIAL MLCSSECT(1,12), 16.92/MLCSSECT(1,23), 29.92
INITIAL MLCSSECT(1,24), .43/MLCSSECT(1,29), 54.66
INITIAL MLCSSECT(1,26), .41/MLCSSECT(1,27), 28.56
INITIAL MLCSSECT(1,28), .39/MLCSSECT(1,32), .38

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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)=22.06
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/S207.41/S208.2/S209.52
REAL &FSF  //FAST CONV. SPEED
LET &FSF=60.0
REAL &SSP  //SLOW CONV. SPEED
LET &SSP=10.0
REAL &OSP  //OLD SPEED
LET &OSP=10.0
INTEGER &INV572(100) //FINISHED ENGINE INV
INTEGER &INPROC //IN PROCESS ENGINES FROM JHOOK ON
INTEGER &ESHPD(100) //ENGINES SHIPPED
INTEGER &TRKLD(1000) //TRUCK LOAD
VCHAR*12 &PARTNO(100) //ENGINE PART #
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
JHLEAX EQU 211,F,C,L //J64 LEAK TEST
JHPRO 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
SSTRT EQU 201,C //SSTRT EQU 201,C,L //ASSEMBLY LOAD
INPRO 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

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ACELLS EQU 209,C
//ACTIVE CELLS
FINV EQU 215,C
//FINISHED INVENTORY
TRKHLDS 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 INITIALIZATION 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

SHIP M 207,5
//SHIPPING SCHEDULE
ESYSPRF M 10.5
//MISC. SYSTEM PERFORMANCE
DBSHIPS M H,100,21
//DAILY ENGINE SHIIPMENTS
TSHIPS M H,100,21
//DAILY TRUCK BY CUSTOMERS
SDLAY M L,100,5
//SHIIPMENT DELAYS
SEQVAR M L,100,5
//SEQUENCE VARIATION
PROTIME M L,100,5
//PROCESS TIME TO WH
WHSETIM M L,100,5
//WAREHOUSE TIME
GRIDTIM M L,100,5
//GRID TIME BY CUSTOMER
TRKLDTIM M L,100,5
//TRUCK LOAD TIME BY CUSTOMER
FINSEQ F 0 V A R I A B L E P F(SSEQN)-4FINORD
//ENGINE SEQ VS. FINISH ORDER

TTPS Project Inputs

REAL &ASMMAX
//ASSEMBLY MAXIMUM
REAL &JHSPD(3)
//J-HOOK SPEED/SHIFT
REAL &PERF(10)
//TECH. PERFORMANCE/MODULE
REAL &JHKL
//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 &HRPTIM
//HEAVY REPAIR TIME
REAL &LRPTIM
//LIGHT REPAIR TIME
REAL &CRPTIM
//CELL REPAIR TIME
REAL &LPRRAJ
//LIGHT REPAIR REJECT%
REAL &CRPRRAJ
//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 &CTRIM(100)
//568 COMPRESSOR TRIM
REAL &BTRIM(100)
//568 BLUEBIRD TRIM
REAL &RPASS(110)
//REAL DATA INPUT VARIABLE
REAL &COPTN(100)
//COMPRESSOR OPTIONS
REAL &CTEST(100)
//TEST CELL CYCLE TIME
REAL &HHOOK(100)
//TEST CELL HOOK TIME
REAL &CNHK (100)
//TEST CELL UNHOOK
REAL &RHOOK(100)
//RTIME FOR TEST CELL HOOK
REAL &RTOORK(100)
//RETORQUE TIME/ENGINE
REAL &TRJRT(100)
//1ST TEST REJECT%
REAL &TRJRT(100)
//2ND TEST REJECT%
REAL &BLOWO(100)
//PAINT MASK & BLOW-OFF
REAL &MARK(100)
//MASK TIME
REAL &PCATG(100)
//PRIME COAT CYCLE TIME
REAL &TCATG(100)
//TOP COAT CYCLE TIME
REAL &RECTRKS
//# REC'D TRUCKS/DAY
REAL &SHPTIM(10)
//572 CYCLE TIMES
REAL &FLASH
//PAINT FLASH TIME/STOP
REAL &COOL
//PAINT COOL TIME/STOP
REAL &PPFSP
//PAINT DELIVERY SPEED
REAL &PNTSSP
//PAINT PROCESS CHAIN SPEED
REAL &INSPCT
//INSPECT TIME
REAL &CYADJ
//CYCLE TIME ADJUST
REAL &EPROD(10)
//ENGINE PRODUCTION BY MODULE
INTEGER &LBCTJNK
//# J-HOOK CARRIERS
INTEGER &ANMOD
//# ENGINE MODELS
INTEGER &ATCRTE(100)
//TEST CELL ROUTING(0=ANY)

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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 &EPCNT(100) //ENGINE OPTION COUNT
INTEGER &ENG1(100) //ENGINE COUNT (1ST TEST)
INTEGER &ENG2(100) //ENGINE COUNT (2ND TEST)
INTEGER &MD //MODULE POINTER
INTEGER &SF //SHIFT POINTER
INTEGER &LOC(6) //LOCATION PARAMETER
INTEGER &WDAYS(10) //WORKS DAYS/WEEK/MODULE
INTEGER &WEEK //# PRODUCTION DAYS/WEEK
INTEGER &GCSTLS //CUSTOM TRIM LAST STATION
INTEGER &FNTLS //FINAL TRIM LAST STATION
INTEGER &ECLASI(100) //ENGINE CLASS INTEGER BY ENGINE
INTEGER &BLIM //BACKBONE LIMIT
INTEGER &ATHEAD //AT HEAD OF ATTIC
VCHAR * 20 &CUSTMR(100) //CUSTOMER BY ENGINE
VCHAR * 20 &CUSTID(100) //CUSTOMER ID (UNIQUE)
VCHAR * 20 &DATE //PREVIOUS SHIP DATE
VCHAR * 20 &TRUCK //PREVIOUS TRUCK #
VCHAR * 20 &STECH(10) //SHIPPING TECHNICIANS
VCHAR * 20 &MODID(10) //MODULE ID NAME
VCHAR * 20 &TECHN(100) //TECHNICIAN NAME
VCHAR * 10 &CPASS(10) //CHARACTER VALUE PASS
VCHAR * 10 &SNAME(300) //STATION NAME
VCHAR * 10 &ECLAST(20) //ENGINE CLASS CHAR-DEFINITION

* VARIABLE DEFINITION

CTRL FVARIABLE MLSCECT(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)
CEL51 VARIABLE (BV1=1)OR(BV2=1)OR(BV3=1)OR(BV4=1)OR(BV5=1)OR(BV6=1)
TOSTO VARIABLE PF(RJCT)=1
TORPR VARIABLE (PFJRJCT=1)AND(SNF32) //TO REPAIR
RQRW Variable (FNJ2)AND(SNF1)AND(Q13=0) //RETORQUE REWORK
OPMR VARIABLE PF(PTR)'GE'11*PF(PTR)'LE'13
PTWAY VARIABLE XF79'E':PF1+XF80'E':PF1
B17 Variable (SP053)+S(SPNT4)'L'2
SFTCO VARIABLE (PFSPHT=1)AND(PFMOD=AMCD) //SHIFT CHANGEOVER
DLAY1 VARIABLE (PFSCLOC=LOC(1))OR(PFSCLOC=LOC(2))OR(PFSCLOC=LOC(3))OR_ (PFSCLOC=LOC(4))OR(PFSCLOC=LOC(5))OR(PFSCLOC=LOC(6))
PBATCH VARIABLE (CH(SPNT3)>=21)AND(SE(SPNT4))AND(SE(SPNT5))
RTQUL VARIABLE (LS38)AND(LS39)
ENG15 VARIABLE (&ECLASI(PFSENGINE)=10)OR_
(&ECLASI(PFSENGINE)=11)OR_
(&ECLASI(PFSENGINE)=12)OR_
(&ECLASI(PFSENGINE)=13)
RTQBYP VARIABLE (PF(PCODE)=PMTSYS)OR(PF(ENGINE)=0)
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, 50/14, 42/15, 36/16, 29/17, 21/18, 15

5 FUNCTION PFSDELRT, D18 "OUT" PATH TRAVEL TIME
1, 06/2, 14/3, 2/4, 27/5, 12/6, 40/7, 07/8, 15/9, 2/10, 28
11, 33/12, 41/13, 07/14, 14/15, 20/16, 28/17, 31/18, 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, 8/14, 7/17, 6
20, 5/25, 4/33, 5/30, 2

13 FUNCTION PF(PCT), D39 //SECONDARY %
12, 0/13, 200/14, 0/15, 200/16, 400/17, 0/18, 199/19, 200/20, 0/21, 133/22, 199/23, 33
24, 499/25, 0/26, 125/27, 143/28, 200/29, 250/30, 132/31, 500/32, 1000/33, 0/34, 25, 499
46, 667/47, 999/48, 1249/49, 2499/50, 0

TLOC1 FUNCTION PF(LCTR1), L6
,PRO110/, PRO120/, PRO130/, PRO140/, PRO150/, PRO160

TLOC2 FUNCTION PF(LCTR1), W6 //TECHNICIAN LOCATION #1
,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) = 'F1'
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'
**CONTROL STATEMENT PLUGS-INS**

INSERT <CNTLDEF1.GPS>  // ANIMATION MACROS

**TECHNICIAN TO ELEMENT MATCH-UP MACRO**

FNDTCH STARTMACRO A
ALTERUCHE APOOL, 1, CLOCSPF, PFSCLOC, #A, PFSCLOC, PRO100  // PASS LOC
ALTERUCHE APOOL, 1, CYCLESPF, PLCYCLE, CLOCSPF, PFSCLOC  // PASS CYCLE
BLET PL(CMPET) = PLCYCLE + AC1  // ESTIMATE COMPLETION
UNLINK APOOL, TCH100, 1, CLOCSPF, 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
- &SD= # Simulation Days
- &MSHIFT(10)= Initial Shift/Module
- &MODID(10)= Module Identifier
- &OPXID(200)= Operator ID Index
- &ODPR(200)= Operator Color (Current)/Index
- &SLOW= Start-up Allowance
- &CALOW= Clean-up Allowance
- &EFMIN(10)= # Effective Mins/ Day
- &OPHRS(10)= # Total Hours
- &OPSFT(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
- Matrix TCH1, TCHL= First & Last Technicians (Operators)
- Row= Module
- Col= Shift (1,2,3)

**TIMER CONTROL STATEMENTS**

INTEGER &OPXID(200)  // Operator ID Index
VCHAR+9 &ODPR(200)  // Operator Color (Current)/Index
INTEGER &OPSFT(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
VCAR = 2 &AMPM(2)          //AM/PM START INDICATOR
INTEGER &SD               //' Simulation Days
REAL &SAL0W               //Start-up Allowance
REAL &CAL0W               //Clean-up Allowance
REAL &CLKS                //Simulation Start Time
REAL &CLKPTH              //Clock Path
INTEGER &PS, &PE          //PAINT PURGE/START TIME

TMOIR: FUNCTION MH(HPS, PFS, PF(CTR)), D5
-2.TMRBEG/-1.TMRENDF/15.TMRADV/99.TMRSWG
PCNVRT FUNCTION PF(CTR), E3 //POINTER CONVERT

ADJDL: FVARIABLE MPSWATSPL-(&ACNOOP(PFSMOD)-PLSACBRK) //DELAY ADJUSTMENT
DISPT: BSPECIAL (TFTOP(PFSCTR)<=0) AND (TFTOP(PFSCTR)<=3)
TISFT: BVARABLE (MH(HPS,&I,PFSCTR)>0) AND (MH(HPS,&I,PFSCTR)<=3)
LIMTS: BVARABLE (PFSLOC<&SVAR) AND (PFSLOCNUM>0) //SAME STA. SEARCH

HPS MATRIX MH, 10, 100 //HOURS PER SHIFT DESCRIPTION
TCH1 MATRIX MH, 10, 3 //FIRST TECHNICIAN/MODULE
TCHL MATRIX MH, 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 DEFINITION
* ANYOP FVARIABLE PFSLOC1-PFSLOC2-PFSLOC3-PFSLOC4-PFSLOC5-PFSLOC6
* TBULT FVARIABLE (ML(TECHBD,&I,&J)/ML(TECHBD,&I,7))*FRV(1)/10.0

* DATA READ LOGIC - INPUT SCENARIO

GENERATE ..., 32PF, 7PL //SEED XACT
BGETLIST FILE=INFILE, &TESTID //TEST #
BGETLIST FILE=INFILE, &TESTDESCR //DESCRIPTION
BGETLIST FILE=INFILE, &DUM //SKIP LINE
BGETLIST FILE=INFILE, &PRODVOL(1), &JHS(1) //PRODUCTION-JHSPD/SHIFT
BGETLIST FILE=INFILE, &PRODVOL(2), &JHS(2) //PRODUCTION-JHSPD/SHIFT
BGETLIST FILE=INFILE, &PRODVOL(3), &JHS(3) //PRODUCTION-JHSPD/SHIFT
BLET &ASMAX=6&JHS(1) //ASSEMBLY MAXIMUM

TEST G &JHS(2), &ASMAX, *+2
BLET &ASMAX=6&JHS(2) //ASSEMBLY MAXIMUM

TEST G &JHS(3), &ASMAX, *+2
BLET &ASMAX=6&JHS(3) //ASSEMBLY MAXIMUM

BGETLIST FILE=INFILE, &RUNDAYS //SIMULATION DAYS
BGETLIST FILE=INFILE, &DUM //SKIP
BGETLIST FILE=INFILE, &CLKS //STARTING SIMULATION TIME
BGETLIST FILE=INFILE, &SAL0W //START-UP ALLOWANCE
BGETLIST FILE=INFILE, &CAL0W //CLEAN-UP ALLOWANCE
BGETLIST FILE=INFILE, &LCTMAIN //LOAD BARS IN MAIN SYSTEM
BGETLIST FILE=INFILE, &LCTJHK //LOAD BARS IN J-HOOK SYSTEM
BGETLIST FILE=INFILE, &MAX //MAX* IN TEST CELL LOOP
BGETLIST FILE=INFILE, &CHOK //EXIT TEST LIMIT
BSTORAGE S(TSTLCOUT), &CHOK //SET STORAGE
BGETLIST FILE=INFILE, &CHOK //MAX. CUSTOM TRIM LIMIT
BSTORAGE S(CSTRMCTN), &CHOK //SET STORAGE
BGETLIST FILE=INFILE, &CHOK //MAX. FINAL TRIM LIMIT
BSTORAGE S(FNTRMCTN), &CHOK //SET STORAGE
BGETLIST FILE=INFILE, &CHOK //MAX. PAINT LIMIT

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BSTORAGE S(PAINTCNT),&CHOK  // SET STORAGE
BGETLIST FILE=INFILE,&BLIM   // MAX. BB LIMIT
BGETLIST FILE=INFILE,&JHKO  // JHOOK CHANGEOVER
BGETLIST FILE=INFILE,&JHUL   // UNLOAD JHOOK LINE
BGETLIST FILE=INFILE,&DUM   // SKIP LINE
BGETLIST FILE=INFILE,&LEAKST(1),&LEAKST(2)  // 1ST & 2ND LEAK TEST TIME
BGETLIST FILE=INFILE,&LEAKRJ(1),&LEAKRJ(2)  // 1ST & 2ND LEAK REJECT%
BGETLIST FILE=INFILE,&LEAKRPR(1),&LEAKRPR(2)  // 1ST & 2ND LEAK REPAIR TIME
BGETLIST FILE=INFILE,&DUM   // SKIP LINE
BGETLIST FILE=INFILE,&HRPRTIM // HEAVY 569 REPAIR
BGETLIST FILE=INFILE,&LRPRRJ,&LRPRTIM // 569 LIGHT REJECT & REPAIR TIME
BGETLIST FILE=INFILE,&CRPRRJ,&CRPRTIM // 569 CELL REJECT & REPAIR TIME
BGETLIST FILE=INFILE,&INSPECT // 571 INSPECTION
BCLOSE INFILE

* CUSTOM TRIM

BGETLIST FILE=CRSTM,(&ECLASC(&J),&J=1.14)
BLET &I=0
CUS000 BLET &I=I+1   // NEXT STATION
BGETLIST FILE=CRSTM,END=CUS999,ML(CRSTM,&J,&I),&J=1.14
BLET &CSTLS=&I   // SAVE FOR LAST STATION
TRANSFER ,CUS000
CUS999 BCLOSE CRSTM

* FINAL TRIM

BGETLIST FILE=FNTRM,(&EFAM(&J),&J=1.14)
BGETLIST FILE=FNTRM,&DUM
BLET &I=0
FNL000 BLET &I=I+1   // NEXT STATION
BGETLIST FILE=FNTRM,END=FNL999,ML(FNTRM,&J,&I),&J=1.14
TEST NE &DUM, 'Kit',FNL000
BLET &FNTLS=&I   // SAVE FOR LAST STATION
TRANSFER ,FNL000
FNL999 BCLOSE FNTRM

* STARTING INVENTORY

BGETLIST FILE=INVEN,&DUM // SKIP LINE
BLET &I=0 // ZERO OUT
INV000 BLET &I=I+1 // BUMP
BGETLIST FILE=INVEN,END=INV100,ML(INVEN,&J,&I),&J=1.14
&IN569(&I),&IN570(&I),&IN572(&I),&J,_
&CUSTMR(&I),&DUM1,&ECLAS(&I)
TEST NE &CUSTMR(&I),&PRVCUS,INV005
BLET PF(LOC1)=&I
SPLIT 1,KEY000
&PRVCUS=&CUSTMR(1)
BLET PF(LOC1)=0
INV005 BLET PF(LCTR)=LEN(&DUM) // LAST CHAR IN &DUM
INV010 TEST NE SSG(&DUM,PFSLCTR.1), ',', INV020 // FIND ','
LOOP LCTR=PF,INV010
INV020 BLET PF(LCTR)=PF(LCTR)+1
BLET &PARTNO(1)=SGS(&DUM,PFSLCTR) // TRUNCATE
BLET PF(LCTR)=20
INV030 TEST E &DUM2, &ECLAS(PFSLCTR), INV040 // MATCH?
&ECLAS(&I)=PFSLCTR // SAVE PTR VALUE
TRANSFER ,INV000
INV040 LOOP LCTR=PF,INV030
TRANSFER ,INV000
INV100 BLET &I=I-1
BLET &NOMDLS=&I // SAVE # MODELS
BCLOSE INVEN

BLET PF(LCTR)=100 // LOOPER
BLET PF(INDX)=0 // INDEX
BLET PF(JNDX)=0 // COUNTER
BLET &DUM=' ' // SET TO NULL

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INV110  BLET PF(INDX)=PF(INDX)-1  //BUMP  
  TEST NE &CUSTMR(PFSINDEX),',',INV120  //NULL CUSTOMER  
  TEST NE &CUSTMR(PFSINDEX),&DUM,INV120  
  BLET PF(INDX)=PF(INDX)+1  
  BLET &CUSTID(PFSINDEX)=&CUSTMR(PFSINDEX)  
  &DUM=&CUSTMR(PFSINDEX)  
  INV120  LOOP LCTRSPPF,INV110  
  *------------------------  
  * GET LINEUP  
  *------------------------  
  BGETLIST  FILE=ALINEUP,&DUM  
  BLET &I=0  
  SIP000  BLET &I=&I+1  //BUMP  
  BGETLIST  FILE=ALINEUP,END=SIP100, &DUM,MX(SHIPS,&I,2), MX(SHIPS,&I,4)  
  BLET &K=MX(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,SIP040  
  LOOP LCTRSPPF,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=&CUSTMR(PFSLCTR)  
  BLET PF(LCTR)=50  
  SIP050  TEST NE &DUM1,&CUSTID(PFSLCTR),SIP060  
  LOOP LCTRSPPF,SIP050  
  SIP060  BLET MX(SHIPS,&I,5)=PF(LCTR)  //CUSTOMER ID  
  TRANSFER .SIP000  //GO AGAIN  
  SIP100  BCLOSE ALINEUP  
  *------------------------  
  * GET 568 CYCLE TIMES  
  *------------------------  
  BGETLIST  FILE=DPT568,&DUM  //SKIP LINE  
  BGETLIST  FILE=DPT568,&DUM  //SKIP LINE  
  CYL000  BGETLIST  FILE=DPT568, END=CYL090,&DUM,(&RPASS(&I),&I=1,3)  
  BLET PF(LCTR)+&NOMDLS  
  CYL010  TEST NE &DUM,&PARTNO(PFSLCTR),CYL020  //PART# SEARCH  
  LOOP LCTRSPPF,CYL010  //CHECK MATCH  
  * BPUTPIC  FILE=OUT,&DUM  
  * IN CYL568 NOT FOUND  
  TRANSFER .CYL000  
  CYL020  BLET &I=PF(LCTR)  //SAVE PART#  
  BLET &BTRIM(&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  
  *------------------------  
  BGETLIST  FILE=DPT569,&DUM  //SKIP LINE  
  BGETLIST  FILE=DPT569,&DUM  //SKIP LINE  
  CYL100  BGETLIST  FILE=DPT569, END=CYL190,&DUM,(&RPASS(&I),&I=1,8)  
  BLET PF(LCTR)+&NOMDLS  
  CYL110  TEST NE &DUM,&PARTNO(PFSLCTR),CYL120  //PART# SEARCH  
  LOOP LCTRSPPF,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 &HOOK(&I)=&RPASS(2)  //HOOK-UP TIME  
  BLET &UNH(&I)=&RPASS(3)  //UNHOOK TIME  
  BLET &HHOOK(&I)=&RPASS(4)  //HOOK R-TIME  
  BLET &RTORK(&I)=&RPASS(5)  //RETORQUE TIME  
  BLET &TCRT(&I)=&RPASS(6)  //CELL ROUTING
* Written by G. Rehn
* 6/29/98
* Version 01

------------------------------------------------------------------------
* Input Operation Data
* 
CTM000 BLET AM=6CLS/15-1 //STARTING SEGMENT
TEST E AM,97,*+2 //BEYOND DAY'S END
BLET AM=1
BGETLIST FILE=OPDAT,&DUM,(&OPAS(&J),&J=1,96)
BLET &I=0

CTM010 BLET &I=1
TEST E &DFTOP(&I)=15
TRANSFER ,CTM020
TEST E &OPAS(&I),-1
BLET &DFTOP(&I)=5
TRANSFER ,CTM020
TEST E &OPAS(&I),-1
BLET &DFTOP(&I)=10
TRANSFER ,CTM020
TEST E &OPAS(&I),-1
BLET &DFTOP(&I)=1
TRANSFER ,CTM020
BLET &DFTOP(&I)=CHARSTO1(&OPAS(&I))

CTM020 TEST E &I=56.CTM010
* 
BLET PFCTR)=AM
TEST E &DFTOP(AM),2.CTM040 //SHIFT START?
CTM030 BLET PFCTR)=PFN(PVNVRT) //SEARCH FORWARD
BLET PFCTR)=PFN(PVNVRT) //POINTER CONVERT
TEST NE BV(DISFT),1.CTM060 //FOUND INITIAL?
TEST NE &DFTOP(PFCTR))-1.CTM050 //END?;LOOK BACKWARDS
TRANSFER ,CTM030 //SEARCH FORWARD EVERYTHING ELSE
* 
CTM040 BLET PFCTR)=PFN(PVNVRT) //POINTER CONVERT
TEST NE BV(DISFT),1.CTM060 //FOUND INITIAL SHIFT?
TEST NE &DFTOP(PFCTR))-2.CTM030 //START?;LOOK FORWARD
CTM050 BLET PFCTR)=PFCTR)-1 //REDUCE
TRANSFER ,CTM040
CTM060 BLET &NH&DFTOP(PFCTR)) //STARTING SHIFT
* 
CTM070 BLET &I=0 //RESET
CTM080 BLET &I=9I=-1
BGETLIST FILE=OPDAT,END=CTM130,&MODID(&I),(&OPAS(&J),&J=1,96),&EFMIN(&I),_
&OPHRS(&I),&OPSFT(&I),&WDAYS(&I),&PERF(&I)
TEST G &EFMIN(&I),0.CTM180 //MODULE IN PLAY?
TEST G &WDAYS(&I),&WEEK,**2 //WORK DAYS>WEEK?
BLET &WEEK=&WDAYS(&I) //YES;NEW WEEK DEFINITION
TEST E &OPAS(1),'D',CTM100 //DEFAULT?
BLET &J=0

CTM090 BLET &J=6J=1 //BUMP POINTER
BLET MH(HPS,&I,6J)=&DFTOP(&J)
TEST E &J=96,CTM090
BLET &MSHIFT(&I)=&NH //TAG INITIAL SHIFT
TRANSFER ,CTM180
* 
CTM100 BLET &J=0
CTM110 BLET &J=6J=1
TEST E &OPAS(&J),-1 //BEYOND DAY'S END
BLET MH(HPS,&I,6J)=15
TRANSFER ,CTM120
TEST E &OPAS(&J),-1
BLET MH(HPS,&I,6J)=5
TRANSFER ,CTM120
TEST E &OPAS(&J),-1

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BLET MH(HPS,4I,4J)=10
TRANSFER ,CTM120
TEST E &OPAS(&J),',A',*-3
BLET MH(HPS,4I,4J)=2
TRANSFER ,CTM120
TEST E &OPAS(&J),',E',*-3
BLET MH(HPS,4I,4J)=1
TRANSFER ,CTM120
TEST E &OPAS(&J),',S',*-3 //INDICATES SWING OPERATION
BLET MH(HPS,4I,4J)=99
TRANSFER ,CTM120
BLET MH(HPS,4I,4J)=CHARSTOI(&OPAS(4J))
CTM120 TEST E &I.98,CTM120
BLET PFICTR)=4M
TRANSFER ,CTM120
BLET PFICTR)=PF(CTR)*1 //SEARCH FORWARD
BLET PFICTR)=FN(PCNVRT) //POINTER CONVERT
TEST NE BV(TISPFT),1,CTM160 //FOUND INITIAL?
BLET MH(HPS,4I,PF(CTR)),1,CTM150 //END?'LOOK BACKWARDS
TRANSFER ,CTM130 //SEARCH FORWARD EVERYTHING ELSE
CTM140 BLET PFICTR)=PF(CTR)-1 //REDUCE
TRANSFER ,CTM140
CTM160 BLET 4MSHIFT(4I)=MH(HPS,4I,PF(CTR)) //TAG INITIAL SHIFT
CTM180 TEST E &I.10,CTM080 //FINISH READ
CTM190 BCLOSE UPDAT

* READ IN TECHNICIAN DATA *

BLET PF(PLOC)=0 //ZERO OUT FOR SWING ID
GETLIST FILE=TECHS,＆＆DUM
TIN000 GETLIST FILE=TECHS,END=DIN000,ERR=DIN000,PF(TECHN),＆＆TECHNM(PF$TECHN),～
＆＆DUM,＆＆DUM1,PF(SHTF),＆＆CPASS(&J),＆＆J=1,6)
TEST NE ＆＆TECHNM(PF$TECHN),',O',DIN000
TEST E ＆＆DUM1,,'Y',TIN000 //TECH IN PLAY?
BLET PF(MOD)=10 //MOD SEARCH
TIN010 TEST NE ＆＆DUM,＆＆MODID(PF$MOD),TIN010 //MODULE MATCH
LOOP MODSPF,TIN010 //KEEP LOOKING
TRANSFER ,DIN000
TIN020 BLET PF(LCTR)=6
TIN025 TEST NE ＆＆PASS(PF$LCTR),',O',TIN060
BLET PF(INDEX)=0
TIN030 TEST NE ＆＆PASS(PF$LCTR),＆＆NAME(PF$INDEX),TIN040
TRANSFER ,TIN030
TIN040 BLET PF(PF$LCTR+20)=PF(INDEX)
TIN060 LOOP LCTRSPF,TIN025
TIN070 BLET ＆＆K=V(ANYOP) //SUM OF ALL OPERATIONS
TEST G ＆＆.0,TIN000 //IF ZERO; NO TECH
BLET ＆＆LAST=PF$TECHN
BLET ＆＆TCC=＆TCC-1 //＃TECHNICIAN
BLET MX(TCHASN,PF$TECHN,1)=PF(MOD) //SAVE ASSIGNMENTS
BLET MX(TCHASN,PF$TECHN,2)=PF(SHTF) //SAVE ASSIGNMENTS
BLET MX(TCHASN,PF$TECHN,3)=PF(LOC1) //SAVE ASSIGNMENTS
BLET MX(TCHASN,PF$TECHN,4)=PF(LOC2) //SAVE ASSIGNMENTS
BLET MX(TCHASN,PF$TECHN,5)=PF(LOC3) //SAVE ASSIGNMENTS
BLET MX(TCHASN,PF$TECHN,6)=PF(LOC4) //SAVE ASSIGNMENTS
BLET MX(TCHASN,PF$TECHN,7)=PF(LOC5) //SAVE ASSIGNMENTS
BLET MX(TCHASN,PF$TECHN,8)=PF(LOC6) //SAVE ASSIGNMENTS
TIN080 TEST E MH(TCHL.PF$MOD,PF$SHFT),.G,*.+2 //ANY VALUE HERE?
BLET MH(TCHL,PF$MOD,PF$SHFT)=PF(TECHN)+TCHNS //NO; MUST BE FIRST
BLET MH(TCHL,PF$MOD,PF$SHFT)=PF(TECHN)+TCHNS //CURRENT LAST
BLET ＆＆MODID(PF$MOD),,'569',TIN090 //SWING SHFT?
BLET PF(PLOC)=PF(PLOC)-1 //BUMP COUNTER

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TIN090 SPLIT 1.TCH000 //CREATE XACT
TEST E PF(PLOC).2.**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 .TINO00 //LOOP AGAIN

* DONE INPUTING - INITIALIZE SYSTEM/CREATE REMAINING ACTIVE ENTITIES

DINO00 BCLOSE TECHS
WRITE MACRO TESTID,&TESTID
WRITE MACRO TESTDSR,.TESTDSR
BLET PF(CLCTR)=&LBCTM &ST //TOTAL # LOAD BARS IN SYSTEM
TRANSFER .DIN10

* 572 INVENTORY

DINO10 TEST G &SIN572(PFENGINE)=0.DINO20 //ANY OF THIS ENGINE?
BLET &SIN572(PFENGINE)=&SIN572(PFENGINE) //YES;INIT
SPLIT &SIN572(PFENGINE),FINS60 //ENGINE TO FINISHED
TEST G &SIN572(PFENGINE),0.DINO30 //> 0?
BLET &SIN572(PFENGINE)=&SIN572(PFENGINE) //YES;INIT
PRIORITY - 1.YIELD
PRIORITY 0
DINO20 LOOP ENGINESPF,DINO10 //KEEP LOOPING
WRITE MACRO TVS72,#INV572(100) //INITIALIZE #
BARG MACRO IVB.00.00#INV572(100)
TRANSFER .DIN10

* 570 INVENTORY

DINO30 BLET PF(ENGINE)=&SIN572(PFENGINE) //ENGINE ON FLOOR
BLET PF(PTR)=50 //570 ENGINES ON FLOOR
BLET PF(CTR)=&SIN70(PFENGINE) //AVAILABLE
TEST G PF(CTR).0.DINO40 //> 0?
TEST G PF(PTR).0.DINO45 //FINISHED W/ FLOOR?
BLET PF(PTR)=PF(PTR)-PF(CTR) //REDUCE FLOOR COUNT
TRANSFER .DINO40

* 569 INVENTORY

DINO40 SPLIT 1.IPS000 //TO INSPECT
BLET &INPROC=&INPROC+1 //COUNT IN PROCESS
ENTER EWIPQ
ENTER TOTALQ
ADVANCE .1
LOOP CTRSPF.DINO40
TRANSFER .DIN00
TERMINATE

* 560 TEST GE PFENGINE.99,DINO30 //MORE ENGINES

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BLET &DUM='569'
TRANSFER SBR, FNDMOD, SUBRSPF
BLET PF(ENGINE)=0 // ENGINES

DIN070 BLET PF(ENGINE)=PF(ENGINE)+1
BLET PF (CTR)=&SIN569(PFSENGINE) //#AVAILABLE
TEST G PF(CTR), .0, DIN090 // > 0?
BLET PF(LCTR)=PF(LCTR)-PF(CTR)

DIN080 BLET &INPROC=&INPROC+1 // COUNT IN PROCESS
ENTER EWIPQ
ENTER TOTALQ
GATE SNP 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, FNDMOD, SUBRSPF
BLET PF(ENGINE)=0 // ENGINES

DIN100 BLET PF(ENGINE)=PF(ENGINE)+1
BLET PF (CTR)=&SIN568(PFSENGINE) //#AVAILABLE
TEST G PF(CTR), .0, DIN120 // > 0?
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, ITR000 // CREATE ENGINE
ADVANCE .1 // CLEARANCE
LOOP CTRSPF, DIN110

DIN120 TEST GE PFSENGINE, 99, DIN100 // MORE ENGINES

DIN130 SPLIT 1, CNV000 // START MAIN DELIVERY CONV.
PRIORITY -1, YIELD
PRIORITY 0
SPLIT 1, LIN000 // START ASSEMBLY LINE
PRIORITY -1, YIELD
PRIORITY 0
GATE LS DINIT

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

CLK000 BLET &AMP(1)='AM' // INITIALIZE AM/PM VAR
BLET &AMP(2)='PM' // INITIALIZE AM/PM VAR
BLET PF1=&CLKS/60 // HOURS INITIAL OFFSET
BLET PF2=&CLKS/60 // 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 MORNING 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=(48-PF3)*15
CLK10 BLET PF4=LS(MORN)+1 // AM/PM POINTER
WRITE MACRO DST. &AMP(PF4) // AM/PM INDICATOR
BLET PL1=(PL1/12-PL2/720)*130.85 //HOUR HAND OFFSET
BLET PL2=(PL2/60)*130.85 //MIN. HAND OFFSET
PLONAT MACRO 'HND', YMM, PL2 //INITIAL SET MINUTE HAND
PLONAT MACRO 'HND', YMM, PL1 //INITIAL SET MINUTE HAND
ADVANCE PL3 //INITIAL TIME TO AM/PM SWITCH
CLK020 LOGIC I MORN //INVERT AM/PM
BLET PF4=LS(MORN)+1 //AM/PM POINTER
WRITE MACRO DST, &AMP(PF4) //AM/PM INDICATOR
ADVANCE 720 //NEXT 12 HRS
TRANSFER .CLK020

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**MODULE OPERATION CONTROL**

**TMR000**

TEST G &EFMIN(PFSMOD), 0, TMRST //MOD IN OPERATION?
BLET PF(SHFT)=&MSHIFT(PFSMOD) //YES; GET INITIAL SHIFT
TEST NE PF(MOD), 1, JOP000
TEST NE PF(SHFT), 0, TMRADV //ACTIVE SHIFT?
BLET PF(OPEL1)=MH(TCH1, PFMOD, PFSSHFT) //FIRST FACILITY
BLET PF(OPEL1)=MH(TCH1, PFMOD, PFSSHHT) //LAST FACILITY
FAVAIL PF(OPEL1)-PF(OPEL1) //SHUT EVERYONE OFF
BLET PF(CTR)=ACLKS/15-1 //STARTING SEGMENT
BLET PF(CTR)=FN(PCNVRT) //SET CURRENT SEGMENT VALUE
TEST G PF(CTR), 0, TMRINT //CHECK FOR START/STOP
TEST LE PF(CTR), 1, TMRINT //IN OPERATION?
FAVAIL PF(OPEL1)-PF(OPEL1) //PUT IN PLAY
TRANSFER SBR, FACL, SUBRSPF //CHANGE OPER COLORS

**TMRADV**

ADVANCE 15 //TIME ADVANCE

**TMR010**

BLET PF(CTR)=PF(CTR)+1 //BUMP SEGMENT
BLET PF(CTR)=FN(PCNVRT) //YES; RESET
TRANSFER , FNITMDIR) //PROCEED

**TMRINT**

TEST NE PF(CTR), -2, TMRBEG //0 START SHIFT
FAVAIL PF(OPEL1)-PF(OPEL1) //PUT IN PLAY
TRANSFER SBR, FACL, SUBRSPF //CHANGE TECH COLORS
TRANSFER , FNITMDIR) //PROCEED

* START OF SHIFT

**TMRBEG**

TEST E &SDAY@WEEK, 3, 0, 2 //END OF WEEK?
TEST E &WDAYS(PFSMOD), &WEEK, TMRWKE //YES; WORK THE WEEKEND?
BLET &ACNOOP(PFSMOD)=&ACNOOP(PFSMOD)+&SALOW //START-UP
BLET &ACNOOP(PFSMOD)=&ACNOOP(PFSMOD)+&SALOW//START-UP
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, PFMOD, PFSSHHT), 0, TMR015 //IN OPERATION?
TEST LE MH(HPS, PFMOD, PFSSHHT), 1, TMR015 //NOT A BREAK?
BLET PF(SHFT)=MH(HPS, PFMOD, PFSSHHT) //FOUND NEXT SHIFT
TEST NE PF(MOD), 1, JOP010 //564 MODULE
BLET PF(OPEL1)=MH(TCH1, PFMOD, PFSSHHT) //FIRST FACILITY
BLET PF(OPEL1)=MH(TCH1, PFMOD, PFSSHHT) //LAST FACILITY
FAVAIL PF(OPEL1)-PF(OPEL1) //START-UP
TRANSFER SBR, FACL, SUBRSPF //CHANGE TECH COLOR
BLET &MD=PF(MOD) //SAVE MODULE
BLET &SF=PF(SHFT) //SAVE SHIF
UNLINK IPOOL, TMR030, ALL, BVSSFTCO //SHIFT CHANGE-OVER

**TMR020**

ADVANCE 15- &SALOW //PROCEED
TRANSFER , TMR010

**TMR030**

TEST E &MODID(PFSMOD), '569', TMR040
SPLIT 1, ATS000 //DETERMINE ACTIVE CELLS
TRANSFER , TCH160

**TMR040**

TEST E &MODID(PFSMOD), '569S', TCH160
TEST NE PF(LOC), 2, TCH400

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SPLIT 1,ATS000  //DETERMINE ACTIVE CELLS
TRANSFER ,TCH160

TMRBRK FUNAVAIL PF(OPERA1) - PF(OPERL)  //OPERATOR BREAK
TRANSFER SBR,FUNCLR,SUBRSPPF  //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)=PF(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(OPERA1) - PF(OPERL)  //NO;BACK IN OPERATION
TRANSFER SBR,FACLA,SUBRSPPF
TRANSFER ,FN(TMOIR)

SBREK ADVANCE MH(HPS,PF(MOD),PF(CTR))  //SHORT TMRBRK
BLET &ACNOOP(PFSMOD)=&ACNOOP(PFSMOD)+15
BLET PF(OPERA1) - PF(OPERL)  //BACK IN OPERATION
TRANSFER SBR,FACLA,SUBRSPPF
ADVANCE 15-MH(HPS,PF(MOD),PF(CTR))  //RESUME
TRANSFER ,TMR10

TMREND TEST E &MODID(PFSMOD), '569',**2
UNLINK ACELS,ACTS100,ALL  //ACTIVE CELLS
ADVANCE 15-&CALOW  //CLEAN-UP ALLOWANCE
TEST NE PF(MOD),1,MOP130  //564 CONTROL?
UNLINK POLAY,TMR100,ALL,MODSPF,PFSMOD //REORDER WAITING XACTS
UNLINK NOTCH,TMR100,ALL,MODSPF,PFSMOD //REORDER WAITING XACTS
LOGIC C MATCH
TEST NE &MODID(PFSMOD), '5699',TMR091
BLET PF(CTR)=PF(OPERA1)  //4 OPERATORS
BLET PFSJNDX=PF(OPERA1)  //STARTING OPR. INDEX
TMR080 BLET PFSJNDX=&OPXID(PFSJNDX,TCHNS)  //GET OBJECT ID
TEST G PF(INDX),0,TMR085
SCOLOR MACRO PFSJNDX, BAC'
PREEMPT PF(JNDX),TMR200,CYCLESPF  //INTERRUPT TECH IN ACTION
PRIORITY -1,YIELD
PRIORITY 0
RETURN PF(JNDX)
TMR085 BLET PFSJNDX=PFSJNDX+1  //BUMP POINTER
LOOP LCTRSPF,TMR080  //CONTINUE
UNLINK APOOL,TMR300,ALL,MODSPF,PFSMOD
UNLINK HOLD,TMR150,ALL  //RELEASE HELD XACTS
TMR090 FUNAVAIL PF(OPERA1) - PF(OPERL)  //OPERATOR TMR3RK
ADVANCE &CALOW  //DO CLEAN-UP
BLET &ACNOOP(PFSMOD)=&ACNOOP(PFSMOD)+&CALOW
MARK WAITSPF  //COLLECT STOPPAGE TIME
BLET PF(PTR)=0
TRANSFER ,TMR010

TMR091 BLET PF(JNDX)=PF(OPERA1)
BLET PF(CTR)=1
TRANSFER ,TMR080

* SHIFT CHANGEOVER LOGIC *

TMR100 LINK HOLD,FIFO  //STAGE TEMPORARILY
TMR150 LINK NOTCH,FIFO  //REORDER

TMR200 ALTERUCH E INPRO,1,CYCLESPF,PLSCYCLE,CLCSPF,PFSCLC
ALTERUCH E INPRO,1,OPNUMSPF,PFSOPNUM,CLCSPF,PFSCLC
REMOVE ATECH
RELEASE PF(TECHN)+TCHNS  //NO:RELEASE
BLET PL(CMPEST)=0
UNLINK INPRO,TMR150,1,CLCSPF,PFSCLC
PLON MACRO XIDL,TECHSTG
TMR300 LINK IPOOL,FIFO

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TMRSWG UNLINK E APOOL, TCH500, 1, TECHNSPF, (PFSPER1-TCHNS), TMR400
TRANSFER . TMRADV
TMR400 ALTER E ATECHS, 1, OPER1SPF, -99, TECHNSPF, (PFSPER1-TCHNS)
TRANSFER . TMRADV

• WEEKEND STOPPAGE

TMRWKE BLET PF1=SDAY
ADVANCE 1440
TEST NE PF1=SDAY
TRANSFER . TMRSEG

• DETERMINE ACTIVE CELLS

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

ATS050 GATE LC PF(DELRT), ATS030 //ALREADY ACTIVE?
LOGIC S PF(DELRT) //NO: NOW IS
GATE LS 81, ••2
LOGIC C 91
GATE LS 87, ••2
LOGIC C 97
BLET PF(DELRT) = PF(DELRT) - 40 //ADJUST POINTER
LINK ACELLS, FIFO //ON ACTIVE CHAIN
ATS100 LOGIC C PFIDELRT) - 40 //RESET TO INACTIVE
TERMINATE

• TECHNICIAN COLOR SUBROUTINES

FACLR TEST NE PF(MOD), 1, JOP120 //564?
BLET PF(LCTR) = PF(OPPER1) - PF(OPPER1) - 1 //OPS OPERATORS
BLET PF$INDX = PF(OPPER1) //STARTING OPR. INDEX
CLR010 BLET PF$INDX = PF$INDX + PFXID(PFSJNDX-TCHNS) //GET OBJECT ID
TEST G PF(INDEX), 0, CLR015
SCOLOR MACRO PF$INDX = &OPXID(PFSJNDX-TCHNS)
CLR015 BLET PF$JNDX = PF$JNDX - 1 //BUMP POINTER
LOOP LCTRSPF, CLR010 //CONTINUE
TRANSFER . PF(SUBR) - 1 //RETURN

FUNCLR TEST NE PF(MOD), 1, JOP110 //564?
BLET PF(LCTR) = PF(OPPER1) - PF(OPPER1) - 1 //OPS OPERATORS
BLET PF$INDX = PF(OPPER1) //STARTING OPR. INDEX
CLR020 BLET PF$INDX - PF$INDX + PFXID(PFSJNDX-TCHNS) //GET OBJECT ID
TEST G PF(INDEX), 0, CLR025
SCOLOR MACRO PF$INDX = 'LAYOUT'
CLR025 BLET PF$JNDX = PF$JNDX - 1 //BUMP POINTER
LOOP LCTRSPF, CLR020 //CONTINUE
TRANSFER . PF(SUBR) - 1 //RETURN

TMRSSTP TERMINATE //INACTIVE MODULE

• KEY OBJECT CREATION

KEY000 BLET &KEYCNT = &KEYCNT + 1
CREATE MACRO KEY, XID1
WRITEO MACRO KEYID, XID1, &CUSTMR(PFSLOC1)
SCOLOR MACRO XID1, &CLR(PFSLOC1)
BLET PF(LOC2) = 250 - (10 * &KEYCNT)
PLACEAT MACRO XID1, 0, PFSLOC2
TERMINATE

• 564 SPECIAL CONTROL

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JOPO00 BLET PF(OPER)=200 //FIXED 1ST
LET PF(OPER)=260 //FIXED LAST
BLET PF(CTR)=KCLKS/15+1 //STARTING SEGMENT
BLET PF(CTR)=PN(PCVRST)
BLET PF(CTR)=M(HPS,PF(MOD),PF(CTR)) //CURRENT SEGMENT VALUE
FUNVAIL PF(OPER)=PF(OPER)
SPSPD MACRO JHK6,0
SPSPD MACRO JHK7,0
BLET &SSP=#HSPD(1) //INITIAL SPEED
TEST NE PF(PTR),0,TMRAV //OFFSHIFT START
TEST LE PF(PTR),1,TMRAV //ON BREAK START
TEST NE PF(PTR),2,TMRBEG //BEGINNING SHIFT START
FAVAIL PF(OPER)=PF(OPER) //ALL ELSE IN PLAY
 Blet &SSP=#HSPD(1) //SET SPEED
SPSPD MACRO JHK6,&SSP
SPSPD MACRO JHK7,&SSP
TRANSFER ,PN(TMDIR)
* //LOOP PARAMETER
JOPO10 BLET PF(LCTR)=260
FAVAIL PF(OPER)=PF(OPER) //PUT IN PLAY
JOPO20 TEST GE PF(LCTR),212,JOP030
PREEMPT PF(LCTR),JOP030.CYCLESPL //PREEMPT & SAVE CYCLE
LOOP LCTRSPF,JOP020
JOPO30 PRIORITY -1,YIELD
PRIORITY 0
BLET PF(LCTR)=260 //RETURN CONTROL
JOPO40 TEST GE PF(LCTR),212,JOP050
RETURN PF(LCTR)
LOOP LCTRSPF,JOP040
JOPO50 ALTERCH NE 212,ALL.SHFTSPF,PFSSHFT,SHFTSPF,PFSSHFT
BLET &CYADJ=SSP/&HSPD(PFSSHFT) //ADJUST TO NEW LS
UNLINK 212,JOP060,ALL
BLET &SSP=#HSPD(PFSSHFT)
SPSPD MACRO JHK6,&SSP
SPSPD MACRO JHK7,&SSP
TRANSFER ,TMR020 //RETURN
*
JOPO60 BLET PL(CYCLE)=PL(CYCLE)*)&CYADJ //ADJUST TIME
TEST E PL(ITIME),1,JHK035 //DIRECT ACCORDING TO STATUS
TRANSFER ,JHK031
*
JOP100 LINK 212,FIFO
*
JOP110 ADVANCE 0
SPSPD MACRO JHK6,0
SPSPD MACRO JHK7,0
TRANSFER ,PF(SUBR)+1
*
JOP120 ADVANCE 0
SPSPD MACRO JHK6,&SSP
SPSPD MACRO JHK7,&SSP
TRANSFER ,PF(SUBR)+1
*
JOP130 ADVANCE 0
SPSPD MACRO JHK6,0
SPSPD MACRO JHK7,0
TRANSFER ,TMR090
*
* INITIALIZATION STATUS
*
ITT000 ENTER SOUT
CREATE MACRO LBR,XIDL
SCOLOR MACRO XIDL,&ECLR(PF$ENGINE)
PLON MACRO XIDL,OUT
* TRANSFER ,ITT100
*
ITC000 ENTER SPI
CREATE MACRO LBR,XIDL
SCOLOR MACRO XIDL,&ECLR(PF$ENGINE)

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PLON MACRO XIDI,Pl
* TRANSFER ,CNV100
*
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)=XIDI //SAVE XACT#  
CREATE MACRO TECH,XIDI
WRITEO MACRO TID,XIDI,PF(TECHN)
PLON MACRO XIDI,TECHSTG
TEST E PF(SHIFT).&MSHIFT(PFSMOD),TCH010
BLET &OPCR(PFSTECHN)="Lay"  
SCOLOR MACRO XIDI, 'LAY'
TEST NE PF(SLOC),2,TCH400 //2ND ASSIGNMENT  
SPLIT 1.ATPOS00 //ACTIVE CELL LOGIC  
LINK APOOL,FIFO //PLACE IN ACTIVE POOL  
TCH010 BLET &OPCR(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 PLSOMPST),0,-2  
BLET PLSOMPST) = PL(CYCLE)*AC1  
MARK WAITSPL  
BLET &ACBRK(&ACNOOP(PFSMOD))  
BLET &OPCR(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 &OPCR(PFSTECHN)="WHITE"  
TEST NE PL(CMPST),.-1,TCH120 //HELPER DOESN'T ADJUST COUNT  
BLET &TECHC(PFSLOC) &TECHC(PFSLOC) -1  
UNLINK INPRO, PRO220,1,CLOCSPF .PFSLOC //FREE ELEMENT  
PRIORITY -1,YIELD  
PRIORITY 0  
TCH120 RELEASE PF(TECHN)-TCHNS //NO;RELEASE  
BLET PL(CMPST) = 0 //RESET HELPER INDICATOR
REMOVE ATECHS
*  
BLET PLSWAIT=MPSWTPSPL-(&ACNOOP(PFSMOD))-PLSACMBRK //OP TIME  
BLET PF(NOOPR)=26  
TCH130 TEST NE PF(CLOC),PF(PFSNOOPR),TCH140  
LOOP NOOPR PF(TCH130)
TCH140 BLET PF(NOOPR) = PF(NOOPR) -20  
BLET ML(TECHBD,PFSTECHN,PFSTRMG)=ML(TECHBD,PFSTECHN,PFSTRMG) - PLSWAIT  
BLET ML(TECHBD,PFSTECHN,7)=ML(TECHBD,PFSTECHN,7) + PLSWAIT  
TEST NE PF(OPR1),.-99,TCH500 //TAGGED TO MOVE?  
*  
TCH160 TEST NE CH(NOTCH),0,TCH300 //NO;ANY DELINQUENT UNITS?  
GATE LC MATCH

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LOGIC  S MATCH
BLET &LOC(1)=PFSLOC1
BLET &LOC(2)=PFSLOC2
BLET &LOC(3)=PFSLOC3
BLET &LOC(4)=PFSLOC4
BLET &LOC(5)=PFSLOC5
BLET &LOC(6)=PFSLOC6

UNLINK NOTCH, PRO305, 1, BVDLAY1, ,TCH120
BLET PF(LCTR)=6
TCH161 TEST G &LOC(PFSLCTR), 0, TCH162 // NON 0 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 LCTRSPF, TCH161
TRANSFER , TCH120
TCH163 GATE LC MATCH
UNLINK PDSLAY, PRO310, 1, CLOCSPF, PFSLOC1, TCH170
BLET PF(OPNUM)=PF(LOC1)*1000
LINK APOOL, FIFO
TCH170 UNLINK PDSLAY, PRO310, 1, CLOCSPF, PFSLOC2, TCH180
BLET PF(OPNUM)=PF(LOC2)*1000
LINK APOOL, FIFO
TCH180 UNLINK PDSLAY, PRO310, 1, CLOCSPF, PFSLOC3, TCH190
BLET PF(OPNUM)=PF(LOC3)*1000
LINK APOOL, FIFO
TCH190 UNLINK PDSLAY, PRO310, 1, CLOCSPF, PFSLOC4, TCH200
BLET PF(OPNUM)=PF(LOC4)*1000
LINK APOOL, FIFO
TCH200 UNLINK PDSLAY, PRO310, 1, CLOCSPF, PFSLOC5, TCH210
BLET PF(OPNUM)=PF(LOC5)*1000
LINK APOOL, FIFO
TCH210 UNLINK PDSLAY, PRO310, 1, CLOCSPF, PFSLOC6, TCH300
BLET PF(OPNUM)=PF(LOC6)*1000
TCH300 BLET PL(CMPEST)=0 // ZERO OUT HELPER ID
TEST NE &MODID(PFSMOD), '570', TCH550 // 570 HELPS
TEST NE &MODID(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, PLOCSPF2, // RELEASE ALTER EGO
SCOLOR MACRO XIDL, 'BAC'
PLON MACRO XIDL, TECHSTG
BLET PF(OPER1)=0 // RESET TAG
BLET PF(LCTR)=6 // SEARCH ASSIGNMENTS
TCH510 BLET PF(DELRT)=PF(PFSLCTR+20) // FIND ASSIGNMENT
TEST G PF(DELRT), 40, TCH520 // CHECK FOR CELLS & RTQ
TEST LE PF(DELRT), 63, TCH520
UNLINK ACCELLS, ATS100, 1, DELRTSPF, (PFSDELRT-40)
TCH520 LOOP LCTRSPF, 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 E ATECHS, CLOCSPF, &SVAR, TECHSTPF, CTSPF, TCH560 // GET TECH#
SCAN E ATECHS, CLOCSPF, &SVAR, CMPESTPL, CMPESTPL
TEST G PL(CMPEST), 0, TCH560

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PREEMPT \( \text{PF} (\text{CTR}) + \text{TCHNS} \), TCH110, CYCLESPL //DELAY TECH

SCAN E ATCHS, CLOCSPF, &SVAR, CYCLESPL, CYCLESPL //REMAINING CYCLE
SCAN E ATCHS, CLOCSPF, &SVAR, CLOCSPF, CLOCSPF //GROUP #
BLET PL(CYCLES) = PL(CYCLE) / 2.0 //ADJUST
ALTER ATCHS.1, CYCLESPL, PLSCYCLE, CLOCSPF, &SVAR //PASS CYCLE TIME
ALTER ATCHS.1, CMPESTSPL, 0, CLOCSPF, &SVAR //PASS CYCLE TIME
RETURN \( \text{PF} (\text{CTR}) + \text{TCHNS} \)
BLET PL(CMPEST) = -1
BLET PF(CLOC) = &SVAR
TRANSFER , TCH100

* NEW PAINT PROCESS *

TCH610 ADVANCE 0
PLON MACRO XIDI, PFPASS
ADVANCE PL(CYCLE) //LOOP PAST TWO LOADS
LOOP LCTRSPF, 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 LOC1SPF
TRANSFER , PRO200

* PRO120 ADVANCE 0
FNDTCH MACRO LOC2SPF
TRANSFER , PRO200

* PRO130 ADVANCE 0
FNDTCH MACRO LOC3SPF
TRANSFER , PRO200

* PRO140 ADVANCE 0
FNDTCH MACRO LOC4SPF
TRANSFER , PRO200

* PRO150 ADVANCE 0
FNDTCH MACRO LOC5SPF
TRANSFER , PRO200

* PRO160 ADVANCE 0
FNDTCH MACRO LOC6SPF
PRO200 BLET &TECH(CFSCLC) = &TECH(CFSCLC) - 1 //FOUND TECH
PRO210 LINK INPRO, FIFO //IN PROCESS
PRO220 TRANSFER , PF(SUBR) - 1

* PRO300 MARK WAITSPL //NO TECHS - COLLECT WAIT
BLET PL(ACMBRK) = &ACNOOP(PF$MOD) //ACCUM BREAK TIME
LINK NOTCH, FIFO //NO TECH CHAIN
PRO305 LOGIC C MATCH //1ST DELAY FOUND/FREE MATCH
* PRO305 SPLIT 1, NDL000
LINK PDLAY, FIFO //WAIT 2ND CALL
PRO310 ALTERUCH E APOOL.1, CLOCSPF, PFSCLC, OPNUMSPF, PFSCLC*1000 //PASS ID
ALTERUCH E APOOL.1, CYCLESPL, PLSCYCLE, OPNUMSPF, PFSCLC*1000 //PASS CYCLE
* ALTERUCH E APOOL.1, OPNUMSPF, PFSCLC, OPNUMSPF, CLOCSPF, PFSCLC //PASS OPNUM
BLET PL(CMPEST) = PLSCYCLE + AC1 //ESTIMATES COMPLETION
UNLINK APOOL.1, TCH100, 1, OPNUMSPF, PFSCLC*1000 //GET TECH
BLET PF(OPNUM) = -1 //STOP PICKUP
TRANSFER , PRO200

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

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* ASSEMBLY LAUNCH *

LIN000 SPLIT 1.CLB000 //CREATE JHOOK LOAD BARS
BLET 6S=0 //FOR SHIP SCHEDULE POINTER
BLET &SSP=&JHSPD(1)
SPSPD MACRO JHK5, &SSP
SPSPD MACRO JHK7, &SSP

* READ SCHEDULE LINEUP IN *

LIN010 BLET PF(SEQNM)=PF(SEQNM)+1 //BUMP SCHEDULE
TEST E MX(Ships, PF(SEQNM), 11, 0, ., -2) //SCHEDULE EOF?
  BLET PF(SEQNM)=1 //YES;RESET
TERMINATE
BLET PF(ENGINE)=MX(Ships, PF(SEQNM), 1) //GET ENGINE
BLET PF(TSEQN)=MX(Ships, PF(SEQNM), 4) //TRUCK?
BLET PF(LCTR)=MX(Ships, PF(SEQNM), 2) //# IN RUN

LIN020 BLET PF(SSEQN)=PF(SSEQN)-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 //AWAIT ASSEMBLY LOAD
LDBLK LEAVE 200
TERMINATE

* J-HOOK ASSEMBLY LINE *

CLB000 BLET PF(LCTR)=&LBCTJHK //J-HOOK LOAD BARS
BLET PF(CVSEC)=9 //STARTING POINT
CLB010 GATE LC PF(CVSEC)-JHOOK //FIRST OPEN?
SPLIT 1.JHK000 //CREATE CARRIER
ADVANCE .5 //DELAY
LOOP LCTRSPF,CLB010
TERMINATE

JHK000 GATE LC PF(CVSEC)-JHOOK //CLEARANCE SECTION
LOGIC S PF(CVSEC)-JHOOK
ENTER PF(CVSEC)-JHOOK //ZONE
CREATE MACRO JHLB.XID1
WRITE0 MACRO JID.XID1,'EMPTY'
SCOLOR MACRO XID1,'WHITE'
PLON3 MACRO XID1,JHK,PF(CVSEC)

JHK010 ADVANCE 8.01/FSP //CLEAR LOAD BAR
LOGIC C PF(CVSEC)-JHOOK
ADVANCE (APATH(PF(CVSEC))-8.01)/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, JHK060 //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 XID1,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)=8.01/ &SSP //CLEARANCE & 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 PL(CYCLE)
TRANSFER ,JHK020  // KEEP LOOKING
*
JHK040 GATE LC  212
SELECT  NU  PTR$PF, 212.260  // SELECT A FACILITY
SEIZE  PF(PTR)
JHKTOT BLET  PL(CYCLE) = 14.0 / &SSP  // CLEARANCE @ SLOW
BLET  PL(ITIME) = 1
TEST  NE  &EFAM(&ECLASI(PFENGINE)) , &PRVENG, JHK031
JHKCHG ADVANCE &JHKO
BLET  &JHKOTIM = &JHKO+&JHKCTIM
BLET  &PRVENG = &EFAM(&ECLASI(PFENGINE))
TRANSFER ,JHK031
*
* TRANSFER TO MAIN CONVEYOR
*
JHK050 GATE LS  (PF(CVSEC) - JHOOK), JHK055  // END OF LINE STOPPED?
SPSPD MACRO  JHK6,0
SPSPD MACRO  JHK7,0
LOGIC S  212
FINAVAIL  212-260  // STOP SLOW TRACK
GATE LC  PF(CVSEC) - JHOOK
SPSPD MACRO  JHK6, &SSP
SPSPD MACRO  JHK7, &SSP
FAVAIL  212-260  // STOP SLOW TRACK
JHK054 LOGIC C  212
JHK055 GATE LC  PF(CVSEC) - JHOOK  // CLEARANCE SECTION
LOGIC S  PF(CVSEC) - JHOOK
ENTER  PF(CVSEC) - JHOOK  // ZONE
LEAVE  PF(PLC) - JHOOK
RELEASE  PF(PTR)
PLON3 MACRO  XIDI, JHK, PF(CVSEC)
ADVANCE &APATH(PFSCVSEC) / &FSP  // TRAVEL
GATE LC  451  // J-HOOK DELAY?
SEIZE  210  // JHOOK UNLADER
ADVANCE &JHKUL / &PERF(1)  // UNLOAD TIME
RELEASE  210
BLET  &INPROC = &INPROC - 1  // COUNT ENGINE IN PROCESS
BLET  &EPROD(1) = &EPROD(1) - 1  // COUNT ENGINE RATE
BLET  &PRORATE(1) = &PRORATE(1) - 1
BARG MACRO  RT1, TOP, &PRORATE(1)
ENTER  EWIPQ
ENTER  TOTALQ
MARK  LAPITMPNL  // START TIMING
LOGIC S  ASMUL  // SIGNAL UNLOAD
LINK  ASMUL, FIFO  // WAIT INTERFACE
ULASM LOGIC C  PF(CVSEC) - JHOOK
SCOLOR MACRO  XIDI, 'WHITE'
WRITEO MACRO  JID, XIDI, 'EMPTY'
TRANSFER ,JHK020
*
JHK060 BLET  PF(CVSEC) = 1  // AT FIRST
GATE LC  PF(CVSEC) - JHOOK  // CLEARANCE SECTION
LOGIC S  PF(CVSEC) - JHOOK
ENTER  PF(CVSEC) - JHOOK  // ZONE
LEAVE  PF(PLC) - JHOOK
PLON3 MACRO  XIDI, JHK, PF(CVSEC)
ADVANCE &APATH(PFSCVSEC) / &FSP  // TRAVEL
GATE SNE  200  // BLOCK THERE?
SCANUCH G ASMUL, SSEQNSPF, 0, SSEQNSPF, SSEQNSPF
SCANUCH E ASMUL, SSEQNSPF, PFSSSEQN, ENGINE$PF, ENGINE$PF
SCANUCH E ASMUL, SSEQNSPF, PFSSSEQN, TSEQNSPF, TSEQNSPF
SCANUCH E ASMUL, SSEQNSPF, PFSSSEQN, SEQNSPF, SEQNSPF
BLET  PL(CYCLE) = 440.0 / &PRODVO(1) / &PERF(1)
SEIZE  PF(CVSEC) - JHOOK
ADVANCE PL(CYCLE) * &ASMMAX / &SSP  // UNLOAD TIME

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RELEASE PF(CVSEC)+JHOOK
UNLINK ASMLD,LBLK.1 //GRAB BLOCK
SCOLOR MACRO XIDI,'GREEN'
WRITEO MACRO JID,XIDI,&PARTNO(PFSENGINE)
LOGIC C PF(CVSEC)+JHOOK
TRANSFER .JHKO20

' 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, &PARTNO(PFSENGINE)
  BARG MACRO XIDI,'WHITE'
  GOPF1 ADVANCE 0
  PLON MACRO XIDI,BB18
  ADVANCE 11.22

  GOPF2 LINK 18,FIFO,GOPF2A
  GOPF2A SEIZE SPF2
  ENTER SPF2
  PLON MACRO XIDI,PF2
  ADVANCE 0.1
  LEAVE SPF2
  PLON MACRO XIDI,PL
  ADVANCE 0.17

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

  GATE LC SPF1
  GATE LS ASMUL,BLU100 //GO TEST BLUBIRD IF NO J-HOOK
  GOPF4A GATE LS ASMUL //AWAIT J-HOOK ENGINE?
  SCANUCH G ASMUL,SEQNSPF,0,SEQNPSPF,SEQNPSF //GET GRAND SEQ#
  SCANUCH E ASMUL,SEQNSPF,SEQNPSF,SEQNPSF //GET ENGINE#
  SCANUCH E ASMUL,SEQNSPF,SEQNPSF,SEQPSPQF,SEQNPSF,SEQPSQF
  SCANUCH E ASMUL,SEQNSPF,SEQNPSF,SEQPSPQF,SEQNPSF,SEQNPSPF
  UNLINK ASMUL,ULASP.1 //RELEASE
  LOGIC C ASMUL //AWAIT NEXT ENGINE
  WRITEO MACRO LBRID,XIDI,&PARTNO(PFSENGINE)
  SCOLOR MACRO XIDI,&CLEAR PFSENGINE

* MAIN DELIVERY CONVEYOR

  GOPF5 SEIZE SPO
  ENTER SPO
  PLON MACRO XIDI,P0
  ADVANCE 0.1
  RELEASE SPO
  LEAVE SPL
  LOGIC C SPO
  ADVANCE 0.55
  LINK 211,FIFO,CNVO20
176

CNVO20
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,CNVO30 //BLUEBIRD?
BLET PF(PCODE)=PNTSYS //YES; DIRECT TO PAINT
TRANSFER ,CNVO50 //PROCEED

CNVO10
TEST G &CTRIM(PFENGINE),0,CNVO40 //CARB TRIM
BLET &OPCNT(PFENGINE)=&OPCNT(PFENGINE)+1
BLET PF(CTR)=&OPCNT(PFENGINE) //SAVE
BLET PF(PCT)=&OPCNT(PFENGINE)*100 //SAVE PCT
TRANSFER SBR.RPCT00, SUBR5PF //DETERMINE %
BLET &GBCNT(1)=&GBCNT(1)+1 //REJECT COUNT
BLET PF(CLOSE)=&GBCNT(1) //SAVE COUNT
TRANSFER SBR.RPCT00, SUBR5PF //DETERMINE REJECT
TEST E PF(RJCT),0,RPH000 //PASS TEST?
TEST E PF(DELRT),0,RPH000 //YES; CARB TRIM JOB?
BLET PF(PCODE)=CLTEST //REST TO TEST
CNVO40
ADVANCE &LEAKTST(1)/PERF(1) //NO LEAK TEST
BLET &GBCNT(1)=&GBCNT(1)+1 //REJECT COUNT
BLET PF(CTR)=&LEAKRJ(1)*100 //SAVE PCT
TRANSFER SBR.RPCT00, SUBR5PF //DETERMINE REJECT
TEST E PF(RJCT),0,RPH000 //PASS TEST?
TEST E PF(DELRT),0,RPH000 //YES; CARB TRIM JOB?
BLET PF(PCODE)=CLTEST //REST TO TEST
CNVO50
BLET PF(CVSEC)-1 //STARTING SECTION
GATE LC PF(CVSEC) //ZONE CLEAR
LOGIC S PF(CVSEC) //SHUT OFF
BLET &DUM='569' //GOING 569
TRANSFER SBR.FMDMOD, SUBR5PF //FIND MOD #
ENTER PF(CVSEC) //MERGE ZONE
PLONJ
MACRO XID1.BB.PF(CVSEC)
ADVANCE ML(CSECT,PFSCVSEC,12) //MERGE ZONE
LOGIC C PF(CVSEC) //CLEARANCE
LEAVE SPO //FREE PREVIOUS
RELEASE 211
UNLINK 211.CNVO20,1

PLONJ
MACRO XID1.BB.PF(CVSEC)
TRANSFER ,BBD060

* BACKBONE DELIVERY CONVEYOR
*

BBD000
GATE LC PF(CVSEC) //SWITCH CLEAR
LOGIC S PF(CVSEC) //10TH TIME
TEST NE &BMBG(PFSCVSEC),1,BBD050 //MERGE ZONE?
ENTER PF(CVSEC) //NO; GET ZONE
PLONJ
MACRO XID1.BB.PF(CVSEC)
ADVANCE ,12 //CLEARANCE ZONE
TEST E PF(CVSEC),5, '5-2
TRANSFER SBF.BBD090, SUBR5PF
LOGIC C PF(CVSEC) //OPEN CLEARANCE
LEAVE PF(PLOC) //FREE PREVIOUS
TEST E PF(PLOC),3,'5-2
UNLINK PF(PLOC), BBD000, 1
TEST E PF(PLOC),3, '5-2
UNLINK PF(PLOC), TLC3320, 1
ADVANCE ML(CSECT, PFSCVSEC)-1,12 //ZONE
BBD010
TEST NE PF(CVSEC),1,BBD0100 //GO TO RC?
TEST NE PF(CVSEC),3,BBD0300 //ALL TEST CELLS
TEST NE PF(CVSEC),4,BBD0400 //ALL TEST CELLS
TEST NE PF(CVSEC),5,BBD0500 //TEST CELLS 7-18
TEST NE PF(CVSEC),9,BBD0900 //SPECIAL
TEST NE PF(CVSEC),11,BBD1100 //SPECIAL
TEST NE PF(CVSEC),13,TLC000 //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,G0PF2 //EMPTY LOAD BAR RETURN
BBD020
BLET PF(PLOC)+PF(CVSEC)-1 //SUMP PREVIOUS LOC
BLET PF(CVSEC)+PF(CVSEC)-1 //NEXT ZONE
TRANSFER ,BBD000

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BBD050 ENTER PF(CVSEC)  //MERGE ZONE
PLON3 MACRO XIDL, BBD, PF(CVSEC)
ADVANCE ML(CSECT, PFSCVSEC, 11)  //MERGE ZONE
TEST E PF(CVSEC) 18, *-2
TRANSFER SBR, BBD090, SUBR$PF
BBD055 LOGIC C PF(CVSEC)  //CLEARANCE
LEAVE PF(PLOC)  //FREE PREVIOUS
TEST E PF(PLOC), 3, *-2
UNLINK PF(PLOC), BBD000, 1
TEST E PF(PLOC), 33, *-2
UNLINK PF(PLOC), TLC1220, 1
PLON3 MACRO XIDL, BBD, PF(CVSEC)
BBD060 ADVANCE ML(CSECT, PFSCVSEC, 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) + 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(NOBUKUP), 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, BBD0120
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 SE RECR1, RCL1000  //GO RECIRC IF ATTIC NOT EMPTY
GATE SNF BACKUP, RCL1000  //GO ATTIC IF BACKUP FULL
GATE SNF BACKUP
GATE LC COUNT
TRANSFER SIM, BBD0105, RCL1000  //RETEST IF TRUE/GO ATTIC IF NOT

BBD0300 BLET PF(PLOC) =PF(CVSEC)  //BUMP PREVIOUS LOC
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?
SCAN MIN GCLTEST, TSEQNF$PF, TSEQN$PF, DELRT$PF, CEL006  //FIND LOWEST TRK GRID#
TEST LE PFSTSEQN, PFSEDLRT, BBD000  //AM I LOWEST?
TRANSFER , CEL006

BBD0500 TEST E PF(PCODE), CLTEST, BBD020  //TEST CELL CODE?
GATE SNF 36, BBD20  //ZONE CLEAR?
SCAN MIN GCLTEST, TSEQNF$PF, TSEQN$PF, DELRT$PF, CEL013  //FIND LOWEST TRK GRID#
TEST LE PFSTSEQN, PFSEDLRT, BBD000  //AM I LOWEST?
TRANSFER , CEL013

BBD1600 LINK BACKBCNT, FIFO, BBD1610  //ACCUMULATE BEHIND STOP
BBD1610 GATE LC BACKBCNT  //STOP OPEN?
Enter BACKBCNT
TEST GE S(BACKBCNT), &BBLIM, BBD1620
LOGIC S BACKBCNT
BBD1620 ADVANCE .01
UNLINK BACKBCNT, BBD1610, 1
TRANSFER BBD20

BBD1700 LINK PF(CVSEC), FIFO, BBD1710 // ACCUMULATE BEHIND STOPS
BBD1710 GATE LC BBBSWT
LOGIC S BBBSWT
TEST NE PF(PCODE), 0, BBD020 // 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 BBBSWT
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 TM000

* 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(PFSCVSEC), 1, TLC050 // MERGE ZONE?
ENTER PF(CVSEC) // NO; GET ZONE

PLON3 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 RETORK?
TEST NE PF(CVSEC), 33, TLC3300 // EXIT TL OR REPAIRS

TLC030 BLET PF(PLOC) = PF(CVSEC) // BUMP PREVIOUS LOC
BLET PF(PCODE) = PF(CVSEC) + 1 // NEXT ZONE
TRANSFER TLC010

TLC050 ENTER PF(CVSEC) // MERGE ZONE

PLON3 MACRO XIDI, TL, PFSCVSEC-30
ADVANCE ML(CSECT, PFSCVSEC, 11) // 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 RTORK0, TLC30 // ZONE FULL?
BLET PF(PLOC)=PF(CVSEC) // SAVE PREVIOUS LOCATION
TEST NE PF(ENGINE), 0, RTQ000 // EMPTY EXITS
TEST G PF(PCODE), REPAIRS, TLC30 // REPAIRS STAY ON LOOP?
TEST L PF(PCODE), 10, TLC030 // 1ST PASS 10.5/12.5 STAY ON
SCAN MIN PFSCODE, TSEQNSPF, TSEQNSPF, DELRTSPF, TLC3210
TEST LE PFSTSEQN, PFSDELRT, TLC30

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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 REPRQ, 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(PCVSEC)=3 // CONV. SECTION
GATE LC PF(CVSCE)
LOGIC S PF(CVSEC)
ENTER PF(CVSEC)
PLON MACRO XIDI, 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, FIFO
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 BV1BMRT), 1, GOPF4A /* YES, CONVEYOR FULL?
SCANUCH G BLUBFQ, SSEQNSPF, 0, SSEQNSPF, SSEQNSPF /* GET GRAND SEQ#
SCANUCH E BLUBFQ, SSEQNSPF, PFSSSEQN, ENGINE, ENGINE, ENGINE /* GET ENGINE#
SCANUCH E BLUBFQ, SSEQNSPF, PFSSSEQN, LAPTIMSP, LAPTIMSP
SCANUCH E BLUBFQ, SSEQNSPF, SSEQNSPF, TSEQNSPF, TSEQNSPF
SCANUCH E BLUBFQ, SSEQNSPF, SSEQNSPF, SEQNSPF, SEQNSPF
UNLINK BLUBFQ, BLU010, 1 /* RELEASE
SCOLOR MACRO XIDI, &ECLR1PFENGINE)
WRITEO MACRO LBRID, XIDI, &PFSP ENGINE)
BLET PF(DELRT)=568 /* TAG TO GO TO 568
TRANSFER , GOPF5

* 568 REPAIR AND TRIM

* 568 REPAIR AND TRIM

RPH000 BLET &DUM='568' /* NEW MODULE
TRANSFER SBR, FTNMOD SUBRSPF /* FIND CORRESPONDING #
GATE LC 260 /* CLEARING ZONE
LOGIC S 260 /* STOP
RELEASE 211 /* FREE TEST ZONE
UNLINK 211, CNV20, 1
TEST E PF(RJCT), 1, RPH100 /* NEED REPAIR?
SCOLOR MACRO XIDI, 'RED'
SELECT SNF CLOCSPF, 261, 263 /* OPEN REPAIR SPUR
RPH002 ENTER PF(CLOC)
PLON3 MACRO XIDI, RS, PF(CLOC)-260
ADVANCE .28 /* CLEARING
LOGIC C 260 /* CLEARED
LEAVE SPO
ADVANCE 1.0 /* TO SPUR

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BLET PL(CYCLE) = "LEAKPR(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)

PLON3 MACRO XIDI, RF, PF(CLOC) - 260
ADVANCE .41 + .20 * (263 - PF5CLOC)

RPH005 ENTER LEAKQ
LOGIC C LEAKQ
PLON MACRO XIDI, LEAKTQ
ADVANCE .18
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 PL(CYCLE) = "LEAKTST(2)
TRANSFER SBR, PRO000, SUBR$PF // PROCESS
BLET PF(PCODE) = CTEST // CELL TEST IS NEXT
BLET PF(DELAT) = 0 // ZERO OUT DEL. ROUTE
BLET PF(PLOC) = 270 // LEAK TEST #2
BLET PF(CVSEC) = 19 // SET ZONE
GATE LC PF(CVSEC) // MERGE CLEAR
LOGIC S PF(CVSEC) // YES; TIE UP
ENTER PF(CVSEC)
BLET &DOM = '69
TRANSFER SBR, PNNMOD, SUBR$PF
UNLINK LEAKQ, RPH010.1

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

* BLUEBIRD & COMPRESSOR TRIM

*---------------------------------------------------------------
RPH100 ADVANCE 0
PLON MACRO XIDI, BCTRM0
ADVANCE .28 // CLEARANCE
LOGIC C 260 // CLEAR ZONE
ENTER 271
LEAVE SPO

RPH110 ADVANCE 0
PLON MACRO XIDI, BCTRM1
ADVANCE .79 // TIME
BLET PF(CLOC) = 271 // START OF TRIM LINE
GATE LC PF(CLOC) // @ ASM STATION
LOGIC S PF(CLOC)
BLET PL(CYCLE) = &BTRIM(PFSENGINE)/6/ &PERF(PFSMOD)
TEST E PL(CYCLE), 0, **-2 // NOT CARB?
BLET PL(CYCLE) = &BTRIM(PFSENGINE)/6/ &PERF(PFSMOD)
RPH120 TRANSFER SBR, PRO000, SUBR$PF // PROCESS
BLET PF(PLOC) = PF(CLOC) // SAVE PREVIOUS
BLET PF(PLOC) = PF(CLOC) + 1 // BUMP LOCATION
TEST NE PF(CLOC), 277, RPH150 // END OF LINE?
ENTER PF(CLOC)

PLON3 MACRO XIDI, BCTRM, 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

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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 4
LINK  BACKUP,FIFO
RCL1005  BLET  PF(PCODE)=RCRQ1
ENTER  RECR1  //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  RECR1  //CLEAR ENTRY
ADVANCE 7.53  //UP THE VERTICAL
TEST E  CH(RECR1),0,.*2
BLET  @ATHEAD=PF(TSEQN)  //AT HEAD OF LINK
LINK  RECR1,FIFO
RCL1010  LINK  RECR10,FFIFO,RCL1020  //YES; PUT BACK
RCL1020  ENTER  RECR10
LEAVE  RECR1
BARG  MACRO  PQ2,TOP,100.0*S(RECR1)/(S(RECR1)+R(RECR1))
PLON  MACRO  XIDI,RC12
BLET  @ATHEAD=0
SCANUCH G  RECR10,TSEQNSPF,0,TSEQNSPF,DELRTSPF,RCL1030
TRANSFER  ,RCL1040
RCL1030  SCANUCH G  RECR1,TSEQNSPF,0,TSEQNSPF,DELRTSPF,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,MBB2
ADVANCE .14
LEAVE  RECR10
UNLINK  RECR10,RCL1020,1
PLON  MACRO  XIDI,MBB2

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LOGIC C
   PF(CVSEC)
ADVANCE ML(CSECT,PFS,CVSEC,1) //ON BACKBONE
JOIN GCLTEST
TRANSFER .BBD010

* TEST CELL LOGIC *

CEL006 GATE SFN 34.CELO12
   SCANUCH LE ACELLS,DELRTPSF,6,CELO12 //ANY ACTIVE HERE?
   TEST G &TCRTE(PFENGINE),0,CELO10 //YES;ANY CELL WORK?
   TEST LE &TCRTE(PFENGINE),6,CELO12 //NO;RIGHT RANGE?
   BLET PF(LOC1)=1 //YES;CLEARANCE INDICATOR
   CEL010 ENTER 34 1ST BANK CELL
   LEAVE PFSCVSEC
   REMOVE GCLTEST
   CEL011 BLET PF(CVSEC)=34
PLON MACRO XID1.P34
   ADVANCE .33
   LINK 21,FIFO,FIRST
   CEL012 GATE SFN 35.BBD020
   SCANUCH G ACELLS,DELRTPSF,6,BBD020 //ANY ACTIVE HERE?
   TEST G &TCRTE(PFENGINE),0,CELO20 //YES;ANY CELL WORK?
   TEST G &TCRTE(PFENGINE),6,BBD020 //NO;RIGHT RANGE?
   BLET PF(LOC1)=7
   CEL020 ENTER 35 //CAPTURE EXIT STORAGE
   LEAVE PFSCVSEC //LEAVE ZONE
   REMOVE GCLTEST
   BLET PF(CVSEC)=35
PLON MACRO XID1.P35
   ADVANCE .98 //INDEX
   TRANSFER .CEL040
   CEL013 GATE SFN 36.BBD020
   SCANUCH G ACELLS,DELRTPSF,6,BBD020 //ANY ACTIVE HERE?
   TEST G &TCRTE(PFENGINE),0,CELO30 //YES;ANY CELL WORK?
   TEST G &TCRTE(PFENGINE),6,BBD020 //NO;RIGHT RANGE?
   BLET PF(LOC1)=7
   CEL030 ENTER 36 //CAPTURE EXIT STORAGE
   LEAVE PFSCVSEC //LEAVE ZONE
   REMOVE GCLTEST
   BLET PF(CVSEC)=36
PLON MACRO XID1.P36
   ADVANCE .62 //INDEX
   CEL040 PRIORITY 10
   LINK 22,FIFO,FIRST
FIRST GATE LC PFSCVSEC
LOGIC S PFSCVSEC
   TEST G &TCRTE(PFENGINE),0,TSC050 //GENERAL ASSIGNMENT?
   BLET PF(DELRT)=&TCRTE(PFENGINE) //NO SPECIFIC
TSC000 GATE FS PF(DELRT)=40 //GRAB CELL?
   GATE LS PF(DELRT)=40 //ACTIVE?
   TRANSFER SIM,TSC100,TSC000 //NO;PROCEED
TSC050 TEST E PF(CVSEC),34.TSC080 //NOT;SPECIFIC 1ST DAY RANGE
   BLET PF(LOC1)=1 //1ST CELL
   BLET PF(LOC2)=6 //LAST CELL
   TRANSFER .TSC090 //YES;PROCEED
TSC080 BLET PF(LOC1)=7 //1ST CELL
   BLET PF(LOC2)=18 //LAST CELL
TSC090 SELECT E DELRTPSF,PFSLOC1,PFSLOC2,1,BV
   TEST E PF(DELRT),0.TSC100 //FOUND HOME?
   LOGIC S PF(LOC1)=80 //NO
   GATE LC PF(LOC1)=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

PLONJ
MACRO XIDI,FR,PWSCVSEC
ADVANCE .12
FAYS
BLET XF(COUNT)=XF(COUNT)-1
TEST L XF(COUNT),&MAX,TSC102
LOGIC C COUNT
UNLINK BACKUP,BBD0106,1,.,TSC101
TRANSFER .TSC102
TSC101 UNLINK REC1,RCL101,1
TSC102 ADVANCE 0

PLON3
MACRO XIDI,IN,PF(DELRT)
ADVANCE FN4
RELEASE FN7
BLET PF(CLOC)=PF(DELRT)-40 //LOCATION - DO HOOK-UP
BLET PL(CYCLE)=&HOOK(PFSENGINE)+&RH00K(PFSENGINE)/&PERF(PFSMOD)
TRANSFER SBR,PRO000,SUBRS%PF //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)=&CRPRRT+100 //SAVE PCT
TRANSFER SBR,RPCT00,SUBRS%PF //DETERMINE REJECT
TEST NE PF(RJCT),0,TSC105 //NEED CELL REPAIR?

SCOLOR MACRO XIDI, 'RED'
ADVANCE &CRPRRTM YES; DOWNTIME

SCOLOR MACRO XIDI, &ECLR(PFSENGINE)
TSC105 SEIZE PFSDELRT+100 RUN TIME STATISTICS
ADVANCE &TEST(PFSENGINE)-&HOOK(PFSENGINE)/&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,2,TSC130 2ND TEST?
BLET PF(RETEST)=PF(RETEST)+1 //BUMP COUNT
TEST E PF(RETEST),1,TSC110
BLET &ENGC1(PFSENGINE)=&ENGC1(PFSENGINE)+1 //REJECT COUNT
BLET PF(CTR)=&ENGC1(PFSENGINE) //SAVE COUNT
BLET PF(PCT)=&TRJT1(PFSENGINE)*100 //SAVE PCT
TRANSFER SBR,RPCT00,SUBRS%PF //DETERMINE REJECT
TRANSFER ,TSC120

* MAJOR REPAIR TEST 2ND *

TSC110 BLET &ENGC2(PFSENGINE)=&ENGC2(PFSENGINE)+1 //REJECT COUNT
BLET PF(CTR)=&ENGC2(PFSENGINE) //SAVE COUNT
BLET PF(PCT)=&TRJT2(PFSENGINE)*100 //SAVE PCT
TRANSFER SBR,RPCT00,SUBRS%PF //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)=&LRFRRJ+100 //SAVE PCT
TRANSFER SBR,RPCT00,SUBRS%PF //DETERMINE REJECT
TEST E PF(RJCT),0,TSC200 //NEED CELL REPAIR?
TSC110 BLET PF(RETEST)=0 //CLEAR PARMS
TSC200 MSAVEVALUE PROD+.PFSENGINE,PF$RETEST+3,1,ML COLLECT TEST
MSAVEVALUE PROD+.100,PF$RETEST+3,1,ML //STATS
TEST E PF(RJCT),1,TSC210 //LAST PHASE

SCOLOR MACRO XIDI, 'RED'
TSC210 BLET PL(CYCLE)=&UNHK(PFSENGINE)/&PERF(PFSMOD)
TRANSFER SBR,PRO000,SUBRS%PF //HOOK UP
SEIZE FM11 //EXIT PATH CLEAR

PLON3 MACRO XIDI,OUTB,PF(DELRT)

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ADVANCE .14
RELEASE PF(DELRT)=80 //RELEASE CELL
LOGIC C PF(LOC1)=80 //SIGNAL OPENING
PLON3 MACRO XID1.OUT,PF(DELRT)
ADVANCE FN5
BLET PF(CVSEC)=P Fn3 //32 OR 33
BLET PF(PCODE)=CSTRIM //DEFAULT TO CUSTOM TRIM
TEST E &TCOAT(PFSENGINE),0,"-2 //ANY PAINT STD?
BLET PF(PCODE)=PNTRIM //NO;PC=FINAL TRIM
TEST E PF(ROCT),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 //10.5/12.5'5?
BLET PF(PCODE)=PF(PCODE)-10 //YES;RESET PROCESS CODE
TSC220 GATE LC 60 //METE
LOGIC S 80 //CLOSE OFF
GATE LC PF(CVSEC) //CLEARANCE
LOGIC S PF(CVSEC) //ZONE CLEAR
ENTER PF(CVSEC)
PLON3 MACRO XID1.MTL,(PF$CVSEC-30)
ADVANCE XL(CSECT,PF$CVSEC,12)
RELEASE FN11 //EXIT
LOGIC C 80
LOGIC C PF(CVSEC)
TEST L PF(PCODE)=10,0,"-2 //10.5-12.5 DON'T JOIN HERE
JOIN PF(PCODE) //JOIN GROUP
PLON3 MACRO XID1.TL,PF$CVSEC-30
TRANSFER .TLC040 //ENTER CONV. LOOP
* RETORQUE AREA
*-------------------------------------------
RTQ000 GATE LC RTORKQ //RETOURQUE QUEUE
LOGIC S RTORKQ
ENTER RTORKQ
REMOVE PF(PCODE)
TEST NE BV(RTQBYP),1,RTQ010 //EMPTY OR PAINT?
LEAVE TSTLCOUT
BARG MACRO PQ3.TOP,100.0*(S(TSTLCOUT)/ (S(TSTLCOUT)-R(TSTLCOUT))
RTQ010 ADVANCE 0
PLON MACRO XID1.RTQ0
ADVANCE .12
LEAVE PF(PLOC) //FREE RETORQUE INPUT
LOGIC C RTORKQ
UNLINK PF(PLOC).TLC1205,1
ADVANCE .75
BLET PF(PLOC)=37
LINK RTORKQ,FIFO,RTQ050
RTQ050 TEST NE BV(RTQBYP),1,RTQ100 //BYPASS?
SELECT LC CVSEC$PF,38.39 //PICK PATH
LOGIC S PF(CVSEC)
TEST NE BV(RTQUL),1,"-2
UNLINK RTORKQ,RTQ050.1
PLON3 MACRO XID1.RTQ,(PF$CVSEC-37) //IN TRAVEL
ADVANCE .15 //CONV. TRAVEL
LEAVE PF(PLOC) //STOP 20 REOPENED
ADVANCE XL(CSECT,PF$CVSEC,1) //QUEUE POSITION
ENTER PF(CVSEC)
PLON3 MACRO XID1.RTS,(PF$CVSEC-37)
ADVANCE .14 //MOVE IN
LOGIC C PF(CVSEC)
UNLINK RTORKQ,RTQ050.1 //MAKE OPENING
BLET PF(CLOC)=PF(CVSEC)-23 //STATION ID 61/62
BLET PL(CYCLE)=&RTORK(PFSENGINE)/&PERF(PF$MOD)/2.0
TRANSFER SBR.PRO000_SUBRFPF //PROCESS
SCOLOR MACRO XID1.&ECLR(PFSENGINE)
BLET PF(PLOC)=PF(CVSEC) //SAVE LOCATION
BLET PF(CVSEC)=40 //BUMP LOCATION

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GATE LC PP(CVSEC)
LOGIC S PP(CVSEC)
Enter PP(CVSEC)
ADVANCE .12
LOGIC C PP(CVSEC)
LEAVE PP(PLOC)
ADVANCE ML(CSECT, PF$PLOC, 11) -.12 //REMAINING TRAVEL
BLET PP(PLOC) = PP(CVSEC)
BLET PP(CVSEC) = 15
BLET &EPR0D(3) = &EPR0D(3) + 1 //COUNT ENGINE IN PROCESS
BLET &PR0RAT(2) = &PR0RAT(2) + 1 //COUNT ENGINE RATE

BARG MACRO RT2, TOP, &PR0RAT(2)
BLET &DIM = '570'
TRANSFER SBR, FNDMOD, SUBR$PF
GATE LC PP(CVSEC)
LOGIC S PP(CVSEC)
Enter PP(CVSEC)
PLON3 MACRO XI, MB, PF(CVSEC)
ADVANCE ML(CSECT, PF$CVCVSEC, 12) //MERGE ZONE
TRANSFER .BB005 //RETURN TO BB

RTQ100 BLET PP(CVSEC) = 14 //BACKBONE BYPASS
GATE LC PP(CVSEC)
LOGIC S PP(CVSEC)
Enter PP(CVSEC)
PLON MACRO XI, BB14
ADVANCE .12 //CLEARANCE
LOGIC C PP(CVSEC)
LEAVE PP(PLOC)
UNLINK RTORK, RTQ050, 1 //TAKE NEXT
ADVANCE ML(CSECT, PF$CVCVSEC, 12) -.12
TRANSFER .BB0020

* 569 REPAIRS

RPR000 GATE LC REPRQ //REPAIR QUEUE
LOGIC S REPRQ
ENTER REPRQ
PLON MACRO XI1, RPQ
ADVANCE .12
LEAVE PP(PLOC)
LOGIC C REPRQ
ADVANCE .66
RPR005 SELECT NJ CVSEC$PF, 119, 122 //OPEN SPUR
TEST E PP(CVSEC), 0, RPR010
LINK 14, FIFO //AWAIT
RPR010 SEIZE PP(CVSEC) //GET SPUR
ENTER EREPR //EXIT PATH
PLON3 MACRO XI1, IN, PF(CVSEC)
ADVANCE .1 //CLEARANCE
LEAVE REPRQ //FREE QUEUE
ADVANCE .2 //REMAINING PATH
LEAVE EREPR //CLEAR PATH
BLET PP(PLOC) = PP(CVSEC) -.12 - 265 //LOCATION
TEST E PP(RETEST), 0, RPR050 //MAJOR REPAIR?
BLET PL(CYCLE) = &LRPRTIM //TIME
BLET PP(PCODE) = CSTRIM //DEFAULT TO CUSTOM TRIM
TEST E &TCOAT(PCENGINE), 0, * - 2 //ANY PAINT STD?
BLET PP(PCODE) = FNTRIM //NO; PC = FINAL TRIM
TRANSFER .RPR100
RPR050 BLET PL(CYCLE) = &LRPRTIM //HEAVY REPAIR
BLET PP(PCODE) = CLTEST
RPR100 TRANSFER SBR, PRO000, SUBR$PF //PROCESS TIME
BLET PP(RJCT) = 0 //NOT REJECT
SCOLOR MACRO XI1, XCLR(PCENGINE)
Enter EREPR //PATH CLEAR?
PLON3 MACRO XI1, OUTB, PF(CVSEC) //YES
ADVANCE .09 //BACKOUT
RELEASE PP(CVSEC) //FREE SPUR

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UNLINK 14,RPR005,1 //TAKE NEXT
PLON3 MACRO XIDI,OUT.PF(CVSEC) //OUTBOUND PATH
ADVANCE .3
TEST NE PF(PCODE),CLTEST,RPR110

XXX002 ENTER TSTTCOUT
BARG MACRO PQ3.TOP.100.0*S(TSTLCOUT)/(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,RPR110
BLET XF(COUNT)+XF(COUNT)*1
TEST GE XF(COUNT),-MAX,"-2 //COUNT OUT
LOGIC S COUNT
RPR115 JOIN PF(PCODE) //JOIN NEXT GROUP
PLON3 MACRO XIDI,MBB.PF(CVSEC)
ADVANCE ML(CSECT.PF(CVSEC),12) //MERGE ZONE
TRANSFER BBD055 //RETURN TO BB

* TRIM CONVEYOR
*---------------------------------------------------------------
TRM000 GATE LC STRMI //INPUT ZONE
LOGIC S STRMI //SHUT OFF ZONE
ENTER STRMI //ENTER ZONE
PLON MACRO XIDI,TRMI
ADVANCE .12 //INDEX IN
LOGIC C STRMI //CLEAR
LEAVE SSTGO //FREE STAGE
UNLINK SSTGO,BBD1730,1
ADVANCE 1.57
BLET PF(CVSEC)=PF(PCODE)*20 //TRIM ZONE
LINK STRMI,FIFO,TRM020
TRM020 ENTER PF(CVSEC)
ENTER STRMI
LEAVE STRMI
PLON MACRO XIDI,TRM1
ADVANCE .23
LEAVE STRMI
LEAVE STRMI
UNLINK STRMI,TRM020,1
TRM030 TEST E PF(PCODE),CSTRIM.FNT000 //CUSTOM OR FINAL
*---------------------------------------------------------------
* CUSTOM TRIM
*---------------------------------------------------------------
PLON MACRO XIDI,CTC
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 CSTMCMNT
BARG MACRO PQ4.TOP.100.0*S(CSTMCMNT)/(S(CSTMCMNT)-R(CSTMCMNT))
ADVANCE .15
CST010 TEST LE PF(INDX),&CSTM.CST020
BLET PF(INDX)=BLET PF(CLOC)=CTSTM1-1+PF(INDX) //POSITION
BLET PL(CYCLE)=ML(CSTM, &CLASS (PFSENGINE),PF$INDEX) &PERF (PF$MOD)
TEST G PL(CYCLE),0,CST020
TRANSFER SBR.PRO00,SUBRSPF
CST020 BLET PF(PLOC)=PF(CVSEC)
BLET PF(PCODE)=PF(PCODE)+1
BLET PF(PCODE)=PF(PCODE)+1
ENTER PF(CVSEC)
LEAVE PF(PLOC)
PLON3 MACRO XIDI,CT.PF(INDX)
TEST E PF$INDEX.2,CST030
UNLINK PFSPLOC,CST000,1
CST030 TEST NE PF(CVSEC),1,149,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)
BLET PF(PCODE)=FNTRIM
LINK PF(CVSEC),FIFO,CST120
BLET &PRORATE(3)=&PRORATE(3)-1 //COUNT ENGINE IN PROCESS
BLET &PRORATE(3)=&PRORATE(3) - > - l  //COUNT ENGINE IN PROCESS
BLET PF(PCODE)=PNTSYS
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
BLET &EPROD(4)=&EPROD(4) - > - l  //COUNT ENGINE IN PROCESS
BLET &EPROD(4)=&EPROD(4)
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 $((BACKBCNT)*&BBLIM,***2 //AT CHOKE LIMIT
LOGIC S BACKBCNT  //CLOSE OFF ZONE
PLON3 MACRO XIDI,MBB,PF(CVSEC)
ADVANCE $XIDI,MBB,PF(CVSEC)
TRANSFER $XIDI,MBB,PF(CVSEC)
ADVANCE .12
LEAVE PF(CVSEC)
LEAVE FNTRMCNT
BARG MACRO PQ5,TOP,100.0*S(FNTRMCNT)/(S(FNTRMCNT)+R(FNTRMCNT))
ADVANCE .15
FNT020 TEST NE PF(DELT),99,FNT030
TEST LE PF(INDEX),&FNTLS,FNT030
BLET PF(CLOC)=FTRIM-1*PF(INDEX) //POSITION
BLET PL(CYCLE)=ML(FNLTRM, &ECLASI(PFSENGINE),PFSPCODE)/&PERF(PFSMOD)
TEST G PL(CYCLE),.0,FNT030
TRANSFER SBR,FNDMOD,SUBRSPF
FNT030 BLET PF(PLOC)=PF(CVSEC)
BLET PF(INDEX)=PF(INDEX)-1
BLET PF(CVSEC)=PF(CVSEC)+1
ENTER PF(CVSEC)
LEAVE PF(PLOC)
PLON3 MACRO XIDI,FT,PF(INDEX)
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(DELT),99,FNT030
TEST LE PF(INDEX),&FNTLS,FNT030
BLET PF(CLOC)=FTRIM-1*PF(INDEX) //POSITION
BLET PL(CYCLE)=ML(FNLTRM, &ECLASI(PFSENGINE),PFSPCODE)/&PERF(PFSMOD)
TEST G PL(CYCLE),.0,FNT030
TRANSFER SBR,FNDMOD,SUBRSPF
FNT030 BLET PF(PLOC)=PF(CVSEC)
BLET PF(INDEX)=PF(INDEX)-1
BLET PF(CVSEC)=PF(CVSEC)+1
ENTER PF(CVSEC)
LEAVE PF(PLOC)
PLON3 MACRO XIDI,FT,PF(INDEX)
ADVANCE PF(INDEX),2,FNT040
UNLINK PFSPLOC,FNT010,1

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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$ENGINE),PF$INDX)/&PERF(PFSMOD)
TEST G PL(CYCLE),.0,FNT120
TRANSFER SBR,PR0000.SUBRS$PF

FNT120 SPLIT 1.FIN000 //SEND TO INSPECTION
SCOLOR MACRO XIDI,'WHITE'
WRITEO MACRO LBRID,XIDI,'EMPTY'
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,FN0000.SUBRS$PF
PLON MACRO XIDI,PNT1
ADVANCE .12 //CLEAR LIMIT
LEAVE SSTGO
LOGIC C SPNT1
UNLINK SSTGO,BB01730,1
ADVANCE 2.15

* Washer process chain.
*
* PICT010 GATE LC SPNT2 //TRANSITION TO PROCESS CHAIN
LOGIC S SPNT2
PLON MACRO XIDI,PXR
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.PST010
ADVANCE 49.70/&PNTSSP //REMAINING 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,PR0000,SUBRS$PF
SPLIT 1.PST100 //THROUGH PREP
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,SUBR5PPF
 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 //CAPTURE EXIT STOP
LOGIC S SPNT6
 BLET PL(CYCLE)=&FLASH-MPSDELAYSPL //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 //CAPTURE EXIT STOP
PST044 GATE LC SPNT7 //CAPTURE EXIT STOP
LOGIC S SPNT7
 BLET PL(CYCLE)=&TIMEOVEN-MPSDELAYSPL //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-MPSDELAYSPL //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(PCSENGINE),0,*=2
 BLET PF(DELRT)=99 //TAG AS BLUEBIRD
 BLET PF(CVSEC)=PF(PCODE)*20 //BACKBONE ENTRY

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LINK SPNT8,FIFO,PST050
PST050 ENTER (294+PFSPCODE)
BARG4 MACRO PQ,(PFSPCODE-3),TOP,100.0*½(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

PST110 TEST X (CVSEC),1,TCT120
BLET PF(LCTR)=2
PST110 UNLINK SPNT3,PST020,1
ADVANCE .1
LOOP LCTRSPF,PST110
PST120 TERMINATE

* FINISHED ENGINE DATA

FIN000 TEST NE PF(DELAT),99,BLUO00 //BLUEBIRD ENGINE?
BLET OFLDENGS=OFLDENGS-1
BLET ML(PROD,PFSENGINE,2)=ML(PROD,PFSENGINE,2)+1
BLET ML(PROD,100,2)=ML(PROD,100,2)+1
BLET &FTRMENGS=&FTRMENGS+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 &INVS72(PFSENGINE)=INVS72(PFSENGINE)+1 //COUNT IN
BLET &INVS72(100)=INVS72(100)+1 //COUNT IN TOTAL
BLET &INPROC=&INPROC+1 //COUNT OUT
LEAVE EWIPQ
WRITE MACRO INP,&INPROC
BARG MACRO IPB,RIGHT,4INPR0C
WRITE MACRO IV572,&INV572(100)
BARG MACRO IV3,RIGHT,4INV572(100)
TEST G LAPTIM,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,1)/ML(PROTIME,PFSENGINE,2)
TEST E ML(PROTIME,PFSENGINE,2),1,,'="+3
BLET ML(PROTIME,PFSENGINE,4)=MPSLAPTIMSPL //MAX
BLET ML(PROTIME,PFSENGINE,4)=MPSLAPTIMSPL //MIN
TEST G MPSLAPTIMSPL,ML(PROTIME,PFSENGINE,1),"+2
BLET ML(PROTIME,PFSENGINE,4)=MPSLAPTIMSPL //MAX
TEST L MPSLAPTIMSPL,ML(PROTIME,PFSENGINE,5),"+2
BLET ML(PROTIME,PFSENGINE,4)=MPSLAPTIMSPL //MIN

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

WRITE MACRO SYST,(ML(PROTIME,100,3)/60.0)

* PROCESS COUNT
FIN010 BLET ML(ESYSYRF,1,2)=ML(ESYSYRF,1,2)+1
TEST E ML(ESYSYRF,1,2),1,,'="+2
BLET ML(ESYSYRF,1,5)=&INPROC //MIN
TEST L &INPROC,ML(ESYSYRF,1,5),"+2
BLET ML(ESYSYRF,1,5)=&INPROC //MIN
* FINISH SEQUENCE

BLET &FINORD=FINORD+1 //FINISH ORDER
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 ML(SEQVAR,PFSENGINE,2),1,*+3
BLET ML(SEQVAR,PFSENGINE,4)=VSFINSEQ //MAX
BLET ML(SEQVAR,PFSENGINE,5)=VSFINSEQ //MIN
TEST G VSFINSEQ,ML(SEQVAR,PFSENGINE,4),,**2
BLET ML(SEQVAR,PFSENGINE,4)=VSFINSEQ //MAX
TEST L VSFINSEQ,ML(SEQVAR,PFSENGINE,5),,**2
BLET ML(SEQVAR,PFSENGINE,5)=VSFINSEQ //MIN

* FINISH SEQUENCE 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 ML(SEQVAR,100,2),1,*+3
BLET ML(SEQVAR,100,4)=VSFINSEQ //MAX
BLET ML(SEQVAR,100,5)=VSFINSEQ //MIN
TEST G VSFINSEQ,ML(SEQVAR,100,4),,**2
TEST L VSFINSEQ,ML(SEQVAR,100,5),,**2
BLET ML(SEQVAR,100,5)=VSFINSEQ //MIN

FIN050 MARK LAPTIMSPL //TIME IN TRUCK GRID
BLET PF(LOC2)=0 //ZERO OUT
SELECT E LOC1SPF,51,300,PFSTSEQN,XH,FIN055
JOIN PFSLOC1
TEST E G(PFSLOC1),&TRKLD(PFSTSEQN),FIN060
SPLIT 1,SHP000
TRANSFER .FIN060
FIN055 SELECT E LOC1SPF,51,300,0,XH
BLET XH(PFSLOC1)=PFSTSEQN
JOIN PFSLOC1
BLET PFSLOC2=1
QUEUE TRGRIDS
FIN060 LINK FINV:FIFO //GO INTO INVENTORY
FIN080 LEAVE TOTALQ
REMOVE PFSLOC1
BLET &INV572(PFSENGINE)=&INV572(PFSENGINE)-1
BLET &INV572(100)=&INV572(100)-1

* WAREHOUSE COUNT-MINIMUM
BLET ML(EYSYSPRF,2,2)=ML(EYSYSPRF,2,2)+1
TEST E ML(EYSYSPRF,2,2),1,*+2
BLET ML(EYSYSPRF,2,5)=CH(INV) //MIN
TEST L CH(INV),ML(EYSYSPRF,2,5),**2
BLET ML(EYSYSPRF,2,5)=CH(INV) //MIN

* TOTAL COUNT-MINIMUM
BLET ML(EYSYSPRF,3,2)=ML(EYSYSPRF,3,2)+1
TEST E ML(EYSYSPRF,3,2),1,*+2
BLET ML(EYSYSPRF,3,5)=S(TOTALQ) //MIN
TEST L S(TOTALQ),ML(EYSYSPRF,3,5),,**2
BLET ML(EYSYSPRF,3,5)=S(TOTALQ) //MIN

* COLLECT WAREHOUSE TIME BY ENGINE
FIN090 TEST G PL(LAPTIM),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 E ML(WHSETIM,PFSENGINE,2),1,*+1
BLET ML(WHSETIM,PFSENGINE,4)=MPSLAPTIMSPL //MAX
TEST G MPSLAPTIMSPL,ML(WHSETIM,PFSENGINE,4),,**2
BLET ML(WHSETIM,PFSENGINE,4)=MPSLAPTIMSPL //MAX
TEST L MPSLAPTIMSPL,ML(WHSETIM,PFSENGINE,5),,**2
BLET 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)

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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,100, &SDAY) = MH(DSHIPS,100, &SDAY) + 1
BLET MH(DSHIPS,100, 21) = MH(DSHIPS,100, 21) + 1
WRITE MACRO IV572.4INV572(100)
BLET MH(DSHIPS,PFSENGINE, 21) = 0
WRITE MACRO SPE.MH(DSHIPS,100, 21)
BLET MH(DSHIPS,100, &SDAY) = 0
BLET MH(DSHIPS,100, 21) = 0
BLET 4EPR0D(6) = &EPROD(6) + 1 // COUNT ENGINE IN PROCESS
TEST E PF(LOC2), 1, FIN100

DEPART TOGRIDS
BLET PF(INDX) = MX(DSHIPS, PFSSEQN, 5) // CUSTOMER
BLET MH(TSHIPS, PFSSNDX, 1) = MH(TSHIPS, PFSSNDX, 1) + 1
BLET MH(TSHIPS, PFSSNDX, 21) = MH(TSHIPS, PFSSNDX, 21) + 1
BLET MH(TSHIPS, 100, &SDAY) = MH(TSHIPS, 100, &SDAY) + 1
BLET MH(TSHIPS, 100, 21) = MH(TSHIPS, 100, 21) + 1

* COLLECT GRID TIME BY CUSTOMER

BLET ML(GRIDTIM, PFSSNDX, 1) = ML(GRIDTIM, PFSSNDX, 1) + MPSLAPTIMSPL
BLET ML(GRIDTIM, PFSSNDX, 2) = ML(GRIDTIM, PFSSNDX, 2) + MPSLAPTIMSPL
BLET ML(GRIDTIM, PFSSNDX, 3) = ML(GRIDTIM, PFSSNDX, 3) + MPSLAPTIMSPL
BLET ML(GRIDTIM, PFSSNDX, 4) = ML(GRIDTIM, PFSSNDX, 4) + MPSLAPTIMSPL
BLET ML(GRIDTIM, PFSSNDX, 5) = ML(GRIDTIM, PFSSNDX, 5) + MPSLAPTIMSPL

TEST E ML(GRIDTIM, PFSSNDX, 2) = ML(GRIDTIM, PFSSNDX, 2) + MPSLAPTIMSPL // MAX
BLET ML(GRIDTIM, PFSSNDX, 4) = ML(GRIDTIM, PFSSNDX, 4) + MPSLAPTIMSPL // MAX
BLET ML(GRIDTIM, PFSSNDX, 5) = ML(GRIDTIM, PFSSNDX, 5) + MPSLAPTIMSPL // MIN

TEST G MPSLAPTIMSPL, ML(GRIDTIM, PFSSNDX, 4), * 2
BLET ML(GRIDTIM, PFSSNDX, 4) = ML(GRIDTIM, PFSSNDX, 4) + MPSLAPTIMSPL // MAX
BLET ML(GRIDTIM, PFSSNDX, 4) = ML(GRIDTIM, PFSSNDX, 4) + MPSLAPTIMSPL // MAX
BLET ML(GRIDTIM, PFSSNDX, 5) = ML(GRIDTIM, PFSSNDX, 5) + MPSLAPTIMSPL // MIN

* COLLECT GRID TIME IN TOTAL

BLET ML(GRIDTIM, 100, 1) = ML(GRIDTIM, 100, 1) + MPSLAPTIMSPL
BLET ML(GRIDTIM, 100, 2) = ML(GRIDTIM, 100, 2) + MPSLAPTIMSPL
BLET ML(GRIDTIM, 100, 3) = ML(GRIDTIM, 100, 3) + MPSLAPTIMSPL
BLET ML(GRIDTIM, 100, 4) = ML(GRIDTIM, 100, 4) + MPSLAPTIMSPL
BLET ML(GRIDTIM, 100, 5) = ML(GRIDTIM, 100, 5) + MPSLAPTIMSPL

TEST E ML(GRIDTIM, 100, 2) = ML(GRIDTIM, 100, 2) + MPSLAPTIMSPL // MAX
BLET ML(GRIDTIM, 100, 4) = ML(GRIDTIM, 100, 4) + MPSLAPTIMSPL // MAX
BLET ML(GRIDTIM, 100, 5) = ML(GRIDTIM, 100, 5) + MPSLAPTIMSPL // MIN

BLET ML(GRIDTIM, 100, 4) = ML(GRIDTIM, 100, 4) + MPSLAPTIMSPL // MAX
BLET ML(GRIDTIM, 100, 5) = ML(GRIDTIM, 100, 5) + MPSLAPTIMSPL // MIN

FIN100 TERMINATE

* SHIPING SCHEDULE

SHPO00 BLET PF(DELRT) = 0 // STARTING TRUCK
GATE LC DINIT.SHPO010 // 1ST ONE HERE?
SPLIT 1, SIMC90 // YES; CREATE SIMULATION CONTROL
GATE LS DINIT
SHPO10 BLET PF(INDX) = 0 // REINDEX REGISTER
MARK LAPTIMSP
BLET PF(PTR) = 0 // ZERO OUT
BLET &DUM = '572'
TRANSFER SBR.FNMOD.SUBRSPF
BLET PF(CLOC) = SHIP // SHIP LOCATES ENGINES
BLET PL(CYCLE) = &SHPTIM(1)
TRANSFER SBR.PRO000.SUBRSPF // PROCESS TIME
BLET PF(CLOC) = ANALYST // ANALYSIS PRINTS TAGS
BLET PL(CYCLE) = &SHPTIM(2)
TRANSFER SBR.PRO000.SUBRSPF // PROCESS TIME
BLET PF(CLOC) = SHIP // SHIPPER TAGS ENGINES
BLET PL(CYCLE) = &SHPTIM(3)
TRANSFER SBR.PRO000.SUBRSPF // PROCESS TIME

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ENTER DOCKS //YES;OPEN DOCK DOOR?
BLET PF(CLOC)=TRCK572 //TRUCKERS LOAD TRUCK
BLET PL(CYCLE)=&SHPTIM(4)
TRANSFER SBR,PFOO00,SUBRSPF //PROCESS TIME
BLET PF(CLOC)=CLERK //TRUCKERS LOAD TRUCK
BLET PL(CYCLE)=&SHPTIM(5)
TRANSFER SBR,PFO000,SUBRSPF //PROCESS TIME
LEAVE DOCKS //TRUCK LEAVES DOCK
UNLINK FINV,FNO800,ALL,TSEQNSPF,PFSTSEQ
BLET XH(PF$LOC1)=0

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

* COLLECT TRUCK LOAD TIME IN TOTAL
BLET ML(TRKLDTIM,100,1)=ML(TRKLDTIM,100,1)+MPSLAPTIMSP
BLET ML(TRKLDTIM,100,2)=ML(TRKLDTIM,100,2)+ML(TRKLDTIM,100,2)
BLET ML(TRKLDTIM,100,3)=ML(TRKLDTIM,100,1)+ML(TRKLDTIM,100,2)
BLET TEST E ML(TRKLDTIM,100,2),1,*=3
BLET ML(TRKLDTIM,100,4)=MPSLAPTIMSP //MAX
BLET ML(TRKLDTIM,100,5)=MPSLAPTIMSP //MIN
TEST G MPSLAPTIMSP,ML(TRKLDTIM,100,4),*=2
BLET ML(TRKLDTIM,100,4)=MPSLAPTIMSP //MAX
BLET ML(TRKLDTIM,100,5)=MPSLAPTIMSP //MIN
BLET ML(TRKLDTIM,100,5)=MPSLAPTIMSP

TERMINATE

* REJECT % SUBROUTINE

RPCT00 TEST LE PF(PCT)=50,RPCT50 //>100%
RPCT10 TEST E PFSCTR@FN12,0,RPCT70 //NO;REJECT?
BLET PF(RJCT)=1 //YES;TAG
TRANSFER ,PF(SUBR)=1 //RETURN
RPCT50 TEST NE PF(PCT)=100,PFSSSUBR+1 //100%
TEST E PFSCTR82,0,RPCT60 //50% GET REJECT
RPCT55 BLET PF(RJCT)=1 //YES;TAG
TRANSFER ,PF(SUBR)=1 //RETURN
RPCT60 BLET PF(PCT)=PF(PCT)-50 //REDUCE ORIGINAL BY 50%
TRANSFER ,RPCT10
RPCT70 TEST G FN13,0,(PFSSUBR+1) //2NDARY REJECT ADD?
TEST E PFSCTR@FN13,0,(PFSSUBR+1) //NO;REJECT?
BLET PF(RJCT)=1 //YES;TAG
TRANSFER ,PF(SUBR)=1 //RETURN

* FIND MODULE # SUBROUTINE

FNMOD BLET PF(MOD)=0 //ZERO OUT
FNMOD BLET PF(MOD)=PF(MOD)-1 //BUMP
TRANSFER ,FNDM00
FNDM00 BLET &MODID(PFSMOD),&MODID(PFSMOD)+1 //RETURN IF MATCH
TRANSFER ,FNDM00

* DOWN TIME LOGIC

DWT000 TEST NE PF(JNDX),0,DWT100 //ANY DELAY TIME SPECIFIED?
LINK FAILR,FIFO //HOLD FAILURE PULSES
DWT010 ADVANCE &DELAY1(PFSJNDX) //TIME UNTIL 1ST DELAY
DWT020 LOGIC S 450+PF(INDX) //CREATE DELAY STOPPAGE
SCOLOR3 MACRO DOBY,PF$INDEX, 'RED'
ADVANCE &DTIM(PFSINDEX) //DELAY TIME
SCOLOR3 MACRO DOBY,PF$INDEX, 'BAC'
LOGIC C 450+PF(INDX) //REMOVE BLOCKAGE

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ADVANCE &MTBF(PFINDEX)  //MEAN TIME BETWEEN FAILURE
LOOP LCTRSPF,DWT20  //CONTINUE W/ #DELAYS
DWT100 TERMINATE  //NUMBER COMPLETE

* DAY DEFINITION AND SIMULATION DURATION *

SIMC00 BLET &SDAY=1  //STARTING DAY
LOGIC S DINIT  //RELEASE REST
TRANSFER .SIMC15
SIMC10 BPUTPF &SDAY  //INDICATE MODEL STATUS
Simulating Production Day: 
WRITE MACRO DAY, &SDAY
UNLINK FAIL,DWT010, ALL, JNDXSPF, &SDAY  //FREE DELAYS

SIMC15 ADVANCE L440  //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, &RUNDAYS, SIMC20
TRANSFER .SIMC10  //REPEAT
SIMC20 TERMINATE

* RATE COLLECTION/PLOTTING LOGIC *

PLT000 BLET PF(CLOC)=0
BLET PF(LCTR)=6
PLT010 BLET PL(PFSLOC)=0
LOOP LCTRSPF, PLT010
BLET PL(LOC)=0
SPLIT 5, PLT020, LOC16PF
PLT020 BLET PF(PLOC)+PF(CLOC)
BLET PF(PLOC)=PF(CLOC)+1
TEST E PF(CLOC),25, PLT030
BLET PF(CLOC)=1
BLET PF(PLOC)=0
PLT030 BLET &NUM= &TOCHAR(PFSCLOC)
BLET &NUM= '0' || &NUM
TEST NE PF(LOC),6, PLT040

PLT040 ADVANCE 0
PLT040 MACRO RTPLT, PFSLOC1, &NUM, PFSPLOC, PL(PFSLOC1), PFSCLOC, _
&PRORATE(PFSLOC1), &PCLR(PFSLOC1+1)
TRANSFER SBR, FLOW00, SUBRSPF

PLT050 ADVANCE 60  //WAIT NEXT HOUR
TRANSFER .PLT020

* FLOW METER DATA COLLECTION *

FLOW00 TEST G &PRORATE(PFSLOC1), 0, (PFSUBR+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 , (PFSUBR+1)

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CRITICAL QUEUE DATA COLLECTION

KEYQ00

BLET ML(KEYQUE,PFSLOC1.1)=ML(KEYQUE,PFSLOC1.1)+FN(PROCQ)
BLET ML(KEYQUE,PFSLOC1.2)=ML(KEYQUE,PFSLOC1.2)+1
BLET ML(KEYQUE,PFSLOC1.3)=ML(KEYQUE,PFSLOC1.1)/ML(KEYQUE,PFSLOC1.2)
TEST E ML(KEYQUE,PFSLOC1.2),1,*+3
BLET ML(KEYQUE,PFSLOC1.4)=FN(PROCQ) //MAX
BLET ML(KEYQUE,PFSLOC1.5)=FN(PROCQ) //MIN
TEST G FN(PROCQ),ML(KEYQUE,PFSLOC1.4),**2
BLET ML(KEYQUE,PFSLOC1.4)=FN(PROCQ) //MAX
TEST L FN(PROCQ),ML(KEYQUE,PFSLOC1.5),**2
BLET ML(KEYQUE,PFSLOC1.5)=FN(PROCQ) //MIN
TRANSFER ,.(PFSSUBR+1)

SIMC90 SPLIT 1.SIMC00 //DONE INITIALIZING
SPLIT 1.PLTO00
SIMC99 TERMINATE 1

START 2,NP
RESET
LET &EPROD(1)=0
LET &EPROD(2)=0
LET &EPROD(3)=0
LET &EPROD(4)=0
LET &EPROD(5)=0
LET &EPROD(6)=0
LET &EPROD(7)=0
LET &EPROD(8)=0
LET &PRORATE(1)=0
LET &PRORATE(2)=0
LET &PRORATE(3)=0
LET &PRORATE(4)=0
LET &PRORATE(5)=0
LET &PRORATE(6)=0
LET &JHKCOTIM=0

INITIAL M$PROD(1-100,2-9),0
INITIAL M$ESYSPRP(1-10,1-3),0
INITIAL M$SHIPS(1-100,1-21),0
INITIAL M$STSHIPS(1-100,1-21),0
INITIAL M$FLOWRT(1-6,1-5),0
INITIAL M$KEYQUE(1-6,1-5),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),_,
&LCTMAIN,&HRPRRIM,&LRPRRIM,&LRPRR*100.0,_,
&CRPRRIM,&CRPRR*100.0,&DOCK)

TEST: *
SCENARIO: *
AVG. LINE RATE-1ST: **** ENGINE/SHIFT
AVG. LINE RATE-2ND: **** ENGINE/SHIFT
AVG. LINE RATE-3RD: **** ENGINE/SHIFT
# LOAD BARS - MAIN: ***
HEAVY REPAIR: **** MINS.
LIGHT REPAIR: **** MINS. @ ****% REJECT RATE
CELL DELAY: **** MINS. @ ****% DELAY RATE
# EFFECTIVE DOCKS: **

PUTPIC FILE=OUT,LINES=8,(&SDAY)
RESULTS AFTER: ** SIMULATION DAYS

ENGINE PRODUCTION SUMMARY:

PUTPIC FILE=OUT, LINES=9, &EP0D(1), FLT(&EP0D(1)/&SDAY), _
(&EP0D(4J), FLT(&EP0D(4J)/&SDAY), &J=3, 5), _
&EP0D(7), FLT(&EP0D(7)/&SDAY), _
MH(TSHIPS, 100, 21), FLT(MH(TSHIPS, 100, 21)/&SDAY) _
FLT(&SDAY)

TOTAL AVG./DAY

J-HOOK PRODUCTION: ****** ****** ****** ******
TEST PRODUCTION: ****** ****** ****** ******
CUSTOM TRIM PRODUCTION: ****** ****** ****** ******
FINAL TRIM PRODUCTION: ****** ****** ****** ******
PAINT PRODUCTION: ****** ****** ****** ******
ENGINE SHIPPED: ****** ****** ****** ******
TRUCKS SHIPPED: ****** ****** ****** ******

ENGINE PROCESS SUMMARY:

# ENGINES IN PROCESS/ J-HOOK TO 572: ****** ****** ****** ******
# ENGINES IN 572 (TRUCK GRIDS): ****** ****** ****** ******
# TRUCK GRIDS: ****** ****** ****** ******
TOTAL ENGINES AFTER J-HOOK: ****** ****** ****** ******
TRUCK DOCK USAGE SUMMARY:

PUTPIC FILE=OUT, LINES=4, (ML(PROTIME, 100, &J)/1440.0, &J=3, 5), _
(ML(WHSETIM, 100, &J)/1440.0, &J=3, 5), (ML(TRKLDTIM, 100, &J)/1440.0, _
&J=3, 5))

PROCESS TIME IN DAYS/ J-HOOK TO 572: ****** ****** ****** ******
WAREHOUSE TIME IN DAYS: ****** ****** ****** ******
TRUCK LOAD TIME IN DAYS: ****** ****** ****** ******

ENGINE FINISH SEQUENCE VARIATION: ****** ****** ******

FLOW RATE BY DEPARTMENT:

<table>
<thead>
<tr>
<th>DEPARTMENT</th>
<th>TOTAL PRODUCED</th>
<th># ENGINES</th>
<th># SHIFT</th>
<th>DAYS/ WEEK</th>
<th>EFFECTIVE</th>
<th>CALCULATED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(MINS/ENGINE)</td>
<td></td>
<td></td>
<td></td>
<td>MINS./DAY</td>
<td>FLOW RATE</td>
</tr>
</tbody>
</table>

DO
IF &OPSFT(&I)>0
IF &EP0D(&I)>0
PUTPIC FILE=OUT, (&MODID(&I), &EP0D(&I), FLT(&EP0D(&I)/&SDAY), &OPSFT(&I), _
&WDAYS(&I), &EFMIN(&I), FLT(&EFMIN(&I)*&SDAY/*&EP0D(&I)))

ENDIF
ENDIF
ENDDO
PUTPIC FILE=OUT, LINES=11, NSJHKCHG, FLT(NSJHKCHG)/&SDAY, _
&JHKTOTIM/60.0, JHKTOTIM/60.0/*&SDAY, FLT(_
NSJHKCHG)/NSJHKTOT*100.0

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J-HOOK CHANGEOVERS  TOTAL  AVG./DAY

| # CHANGEOVERS:  | *** | *** |
| CHANGEOVER TIME(HOURS):  | *** | *** |
| % CHANGEOVER:  | *** | *** |

HOURLY FLOW METER SUMMARY (UNITS/HOUR)

<table>
<thead>
<tr>
<th>AREA</th>
<th>AVG</th>
<th>MAX</th>
<th>MIN</th>
</tr>
</thead>
</table>
| DO   | &I=1.5 | IF &I=1 | LET &DUM='JHOOK'
ELSEIF &I=2
LET &DUM='TEST'
ELSEIF &I=3
LET &DUM='CUSTOM TRIM'
ELSEIF &I=4
LET &DUM='FINAL TRIM'
ELSE
LET &DUM='PAINT'
ENDIF
PUTPIC FILE=OUT, &DUM, (ML(DSHPRT,&I,.J), &J=3,5)
ENDDO
PUTPIC FILE=OUT, LINES=5

CRITICAL QUEUE SUMMARY

<table>
<thead>
<tr>
<th>AREA</th>
<th>AVG</th>
<th>MAX</th>
<th>MIN</th>
</tr>
</thead>
</table>
| DO   | &I=1.6 | IF &I=1 | LET &DUM='EMPTY'
ELSEIF &I=2
LET &DUM='ATTIC'
ELSEIF &I=3
LET &DUM='TEST LOOP'
ELSEIF &I=4
LET &DUM='CUSTOM TRIM'
ELSEIF &I=5
LET &DUM='FINAL TRIM'
ELSE
LET &DUM='PAINT'
ENDIF
PUTPIC FILE=OUT, &DUM, (ML(KEYQUE,&I,.J), &J=3,5)
ENDDO
PUTPIC FILE=OUT, LINES=7, &DUM

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>
</table>
| DO     | &I=1.99 | IF MH(DSHIPS,&I,.21)>0
PUTPIC FILE=OUT,.PARTNO(&I), (MH(DSHIPS,&I,.J), &J=1,10), _
MH(DSHIPS,.1,.21)
ENDIF
ENDDO
PUTPIC FILE=OUT, LINES=7, (MH(DSHIPS,100,.J), &J=1,10), _
MH(DSHIPS,100,.21)

TOTAL

DAILY TRUCK SHIPMENT BY CUSTOMER:
CUSTOMER

<table>
<thead>
<tr>
<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>
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<th>TOTAL</th>
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<tr>
<td>DO</td>
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<td>PUTPIC</td>
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<td>ENDIF</td>
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<td>ENDDO</td>
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<tr>
<td>PUTPIC</td>
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</tbody>
</table>

TOTAL: |   |   |   |   |   |   |   |   |   |   |-------|

ENGINE PROCESS DETAIL:

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

ENGINE

<table>
<thead>
<tr>
<th># COMPLETE</th>
<th>AVG.</th>
<th>MAX.</th>
<th>MIN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO</td>
<td>1.99</td>
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</tr>
<tr>
<td>IF</td>
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<tr>
<td>PUTPIC</td>
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<td></td>
</tr>
<tr>
<td>(ML(PROTIME, &amp;I, 1)/60.0, &amp;J=3.5)</td>
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<tr>
<td>ENDIF</td>
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<tr>
<td>ENDDO</td>
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<tr>
<td>PUTPIC</td>
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<tr>
<td>(ML(PROTIME, 100.0, &amp;J)/60.0)</td>
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</tr>
</tbody>
</table>

TOTAL: |      |      |      |

WAREHOUSE TIME (IN HOURS):

ENGINE

<table>
<thead>
<tr>
<th># COMPLETE</th>
<th>AVG.</th>
<th>MAX.</th>
<th>MIN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO</td>
<td>1.99</td>
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<tr>
<td>IF</td>
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<tr>
<td>PUTPIC</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(ML(WHSETIM, &amp;I, 1)/60.0, &amp;J=3.5)</td>
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<tr>
<td>ENDIF</td>
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<tr>
<td>ENDDO</td>
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<tr>
<td>PUTPIC</td>
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<td></td>
</tr>
<tr>
<td>(ML(WHSETIM, 100.0, &amp;J)/60.0)</td>
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</tbody>
</table>

TOTAL: |      |      |      |

TRUCK GRID TIME (AWAITING SHIPMENT) IN HOURS:

CUSTOMER

<table>
<thead>
<tr>
<th># COMPLETE</th>
<th>AVG.</th>
<th>MAX.</th>
<th>MIN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO</td>
<td>1.49</td>
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</tr>
<tr>
<td>IF</td>
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<tr>
<td>PUTPIC</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(ML(GRIDTIM, &amp;I, 1)/60.0, &amp;J=3.5)</td>
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<tr>
<td>ENDIF</td>
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<tr>
<td>ENDDO</td>
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<tr>
<td>PUTPIC</td>
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<td></td>
</tr>
<tr>
<td>(ML(GRIDTIM, 100.0, &amp;J)/60.0)</td>
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</tbody>
</table>

TOTAL: |      |      |      |

TRUCK LOAD TIME IN HOURS:

CUSTOMER

<table>
<thead>
<tr>
<th># COMPLETE</th>
<th>AVG.</th>
<th>MAX.</th>
<th>MIN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO</td>
<td>1.49</td>
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</tr>
<tr>
<td>IF</td>
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<tr>
<td>PUTPIC</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(ML(TRKLDTIM, &amp;I, 1)/60.0, &amp;J=3.5)</td>
<td></td>
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</tr>
</tbody>
</table>

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TECHNICIAN PERFORMANCE BY DEPARTMENT
DEPT: 568
OPERATING DAYS/WEEK: *

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th># ENGINES</th>
<th>AVG. TIME/ENGINE</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DO</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>&amp;I=301,400</td>
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</tr>
<tr>
<td></td>
<td>LET &amp;K=I-300</td>
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</tr>
<tr>
<td></td>
<td>IF MX(TCHASN,&amp;K,1)=2</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>PUTPIC FILE=OUT,&amp;TCHNM(&amp;K),MX(TCHASN,&amp;K,2),FC(&amp;I),FT(&amp;I),_</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>FRV(&amp;I)/10.0</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>ENDIF</td>
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<td></td>
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<tr>
<td></td>
<td>ENDDO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PUTPIC FILE=OUT,LINES=6,&amp;WDAYS(3)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DEPT: 569
OPERATING DAYS/WEEK: *

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th># ENGINES</th>
<th>AVG. TIME/ENGINE</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&amp;I=301,400</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>LET &amp;K=I-300</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>IF (MX(TCHASN,&amp;K,1)=3) OR (MX(TCHASN,&amp;K,1)=8)</td>
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</tr>
<tr>
<td></td>
<td>PUTPIC FILE=OUT,&amp;TCHNM(&amp;K),MX(TCHASN,&amp;K,2),FC(&amp;I),FT(&amp;I),_</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FRV(&amp;I)/10.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ENDIF</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ENDDO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PUTPIC FILE=OUT,LINES=6,&amp;WDAYS(4)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DEPT: 570
OPERATING DAYS/WEEK: *

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th># ENGINES</th>
<th>AVG. TIME/ENGINE</th>
<th>% ULT.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DO</td>
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<tr>
<td></td>
<td>&amp;I=301,400</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LET &amp;K=I-300</td>
<td></td>
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<tr>
<td></td>
<td>IF MX(TCHASN,&amp;K,1)=4</td>
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</tr>
<tr>
<td></td>
<td>PUTPIC FILE=OUT,&amp;TCHNM(&amp;K),MX(TCHASN,&amp;K,2),FC(&amp;I),FT(&amp;I),_</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FRV(&amp;I)/10.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ENDIF</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ENDDO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PUTPIC FILE=OUT,LINES=6,&amp;WDAYS(5)</td>
<td></td>
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</tbody>
</table>

DEPT: 571
OPERATING DAYS/WEEK: *
```
* ENGINES

DO
  &I=301,400
  LET &K=&I-300
  IF 
    MX(TCHASN,&K,1)=5
  PUTPIC
    FILE=OUT,&TCHNM(&K),MX(TCHASN,&K,2),FC(&I),FT(&I),_
    FRV(&I)/10.0
    ************  *       *****       ***       **%
  ENDIF
ENDDO
PUTPIC
  FILE=OUT,LINES=6,&WDAYS(6)

DEPT: 514
OPERATING DAYS/WEEK:

# TRUCKS  AVG. TIME/  % ULT.

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIFT</th>
<th>PROCESSED</th>
<th>TRUCK</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

DO
  &I=301,400
  LET &K=&I-300
  IF 
    MX(TCHASN,&K,1)=6
  PUTPIC
    FILE=OUT,&TCHNM(&K),MX(TCHASN,&K,2),FC(&I),FT(&I),_
    FRV(&I)/10.0
    ************  *       *****       ***       **%
  ENDIF
ENDDO
PUTPIC
  FILE=OUT,LINES=6,&WDAYS(6)

DEPT: 570 PAINT
OPERATING DAYS/WEEK:

# ENGINES  AVG. TIME/  % ULT.

<table>
<thead>
<tr>
<th>TECHNICIAN</th>
<th>SHIFT</th>
<th>PROCESSED</th>
<th>ENGINE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

DO
  &I=301,400
  LET &K=&I-300
  IF 
    MX(TCHASN,&K,1)=7
    IF (MX(TCHASN,4K,3)=PNTTC) OR (MX(TCHASN,4K,4)=PNTTC)
  PUTPIC
    FILE=OUT,&TCHNM(&K),MX(TCHASN,&K,2),FC(&I),FT(&I),_
    FRV(&I)/10.0
    ************  *       *****       ***       **%
  ELSE
  PUTPIC
    FILE=OUT,&TCHNM(&K),MX(TCHASN,&K,2),FC(&I),FT(&I),_
    FRV(&I)/10.0
    ************  *       *****       ***       **%
  ENDIF
ENDIF
ENDDO

** Test Summary **

PUTPIC
  FILE=TSUM,&TESTID,&TESTSCR,CURDATE,FLT(&EPROD(1)/&SDAY),_
  (FLT(&EPROD(6J)/&SDAY),&J=3,5),FLT(&EPROD(7)/&SDAY),_
  FLT(MH(DSHIPS,100,2)),FLT(4SDAY),SA(EWIPQ),SM(EWIPQ),_
  CA(FINV),CM(FINV),SA(TOTALQ),SM(TOTALQ),_
  (ML(PROTIME,100,&J)/1440.0,&J=3,4),_
  (ML(SEQVAR,100,&J),&J=3,5)

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

CLOSE
TSUM
END

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APPENDIX C

Snapshot of Animated Simulation Run