ABSTRACT

An Integrated MRP and Finite Scheduling System to Derive Detailed Daily Schedules for a Manufacturing Shop

by
Sita D. Nathan

Many companies rely on Material Requirements Planning (MRP) to support their Production Scheduling and Control (PS&C) functions. Since MRP does not provide a detailed shop floor schedule, these users have to implement either a third party procedure or an internally developed procedure for shop floor controls. In this thesis we consider a class of user shops which are characterized by the following features:

- Homogenous machines., that is all machines can produce all products.
- Each product requires a setup, but several products may have a common setup.
- MRP requirements are specified on a weekly basis while actual requirements are specified on a hourly basis.

Specifically, we develop a MRP and Finite Scheduling System (MFSS) which calculates the weekly "net change" requirements of products, then generates the detailed daily job order schedules, and finally sequences jobs on machine queues. The objectives of the system are to maximize the utilization of the machines and to minimize setup times. The MFSS was programmed on a personal computer-based system utilizing off-the-shelf relational database software.

An Integrated MRP and Finite Scheduling System to Derive Detailed Daily Schedules for a Manufacturing Shop

by
Sita D. Nathan

A Thesis
Submitted to the Faculty of the
New Jersey Insttute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Manufacturing Engineering

Manufacturing Engineering Division

January 1994

APPROVAL PAGE

Deriving Detailed Daily Schedules for a Manufacturing Shop, from a Weekly MRP Schedule

Sita D. Nathan

Dr. Sanchoy K. Das **Date**
Assistant Professor, Department of Mechanical and Industrial Engineering
New Jersey Institute of Technology

Dr. Nouri Levy **Date**
Associate Professor, Department of Mechanical and Industrial Engineering
New Jersey Institute of Technology

Dr. Raj Sodhi **Date**
Director of Manufacturing Engineering Program
New Jersey Institute of Technology

BIOGRAPHICAL SKETCH

Author: Sita D. Nathan

Degree: Master of Science in Manufacturing Engineering

Date: January 1994

Undergraduate and Graduate Education:

- Master of Science in Manufacturing Engineering,
  New Jersey Institute of Technology , Newark NJ, 1994

- Bachelor of Science in Mechanical Engineering,
  BMS College of Engineering, Bangalore, India, 1987

Major: Manufacturing Engineering

Professional Positions Held

Research Assistant, September 1993 - December 1993, Department of Industrial Engineering, New Jersey Institute of Technology Newark, New Jersey.

Simulation Systems Consultant, September 1989 - June 1990, Catalyst For Change Inc., Dayton Ohio.

Research Assistant, December 1988 - August 1989, Composite Materials Laboratory, University of Dayton Research Institute (UDRI), Dayton Ohio.

This thesis is dedicated to
my husband, son and parents

ACKNOWLEDGEMENT

The author wishes to thank her thesis advisor Dr. Sanchoy K. Das for patiently reviewing the progress of the thesis and helping to plan it efficiently. This thesis would not have been sucessful but for his invaluable guidance.

Special thanks to professors Dr. Raj Sodhi, and Dr. Nouri Levy for serving as members of the committee.

Thanks to my friends Rupal and Ravi Chander and Prashanth for their input.

TABLE OF CONTENTS

Chapter **Page**

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Manufacturing Systems Arena

To survive and be competitive in today's global manufacturing, requires the ability to meet a variety of customer demands. These include high quality products, fast delivery and on-time production with the least cost. Production scheduling plays a very important role in this endeavor. In pursuing these difficult objectives, the improvement of manufacturing operations at all levels have to be addressed. The concept of Computer-Integrated Manufacturing (CIM) is no longer foreign to industry, and the application of robots, flexible manufacturing cells, Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), and Computer-Aided Process Planning (CAPP) are becoming commonplace. Concurrently, to enhance production planning and control activities, many companies are applying a variety of similar advances in computer-based techniques. The field of Manufacturing Systems has assumed a principal role in the utilization of computer-based techniques to effectively schedule and control all operations and/or workloads for the factory.

1.2 The Nature Of The Scheduling Problem

The Production Control function in a manufacturing enterprise has evolved into an important element. Production Control people speak their own language, are computer literate for the most part, and use their own proprietary skills and techniques to develop schedules. Since the factory supervision and operators are not involved in the creation of the schedules, they find it difficult to respond to a schedule which they do not understand. To the foreman or machine operator, they are certainly not straight-forward and seldom address his perspective as to what constitutes efficiency or optimum utilization. Thus, all of the Production Control arguments about the reality or believability of the schedules fall on deaf ears. Due to the complexity of the mathematics or "blind faith" required by those not part of the Production Control profession, there is a significant credibility gap. Thus, even in those cases when there are not unforeseen problems to alter the assumptions upon which the schedule was based, there is a justification problem.

The classical response to the gulf between the pragmatic nature of the factory and the system-based theoretical "purity" of the scheduling office is to provide some minimal education to show that there is a new system and that "everyone must adhere to the plan." In other words, dogma (no matter how well intended) is substituted for effective communication. Edicts to adhere to the plan bridge the educational and technical disparity between the Production Control professionals and the pragmatic factory operators. From the foreman's or operator's viewpoint, the Production Control-derived schedule frequently looks like a statement of wishes. Thus, factory personnel often take the prerogative to prioritize, combine, split -- or even ignore -- the formal schedule.

1.3 Production Scheduling And Control Activity (PS&C)

Production Scheduling and Control (PS&C) is one of the most critical activities in a manufacturing environment. It involves the determination of production quantity and timing of the production output, based on product demand and manufacturing capacity requirements.

The goals of PS&C are the following:

1. Minimize the inventory costs,
2. Meet the customer demand,
3. Maximize throughput, and,
4. Balance the work force.

1.4 Scheduling Rules

Production Scheduling is an age old problem. In the past, it involved the scheduling of personnel and equipment in a work-center to meet the due dates for a collection of jobs. Using a set of heuristic priority rules, which allocated jobs to machines in a particular sequence, this problem was resolved. Some examples of the sequencing rules for the multiple-job single machine problem are the following:

- SPT (Shortest Processing Time),
- EDD (Earliest Due Date),
- CR (Critical Ratio), and
- FCFS (First Come First Served).

The selection of these rules depends primarily upon the scheduling objectives of the shop managers. The objective might be *customer-satisfaction oriented* (meet due dates, minimize lateness of jobs) or it might be *performance oriented* (reduce WIP inventory, minimize worker idle time, maximize throughput). Finding a scheduling rule that satisfies a combination of these objectives is difficult. Each of these scheduling rules is uniquely advantageous to meet certain objectives. Specifically, scheduling jobs in their increasing order of their processing times on a machine (SPT) minimizes the mean flow time of the jobs, the mean waiting time of the jobs and the mean lateness of the jobs. Scheduling jobs according to their increasing order of due dates (EDD) minimizes the maximum lateness of the jobs.

Johnson's algorithm (Johnson, 1954) which renders the optimal solution for scheduling multiple jobs on two machines is one of the first reported scheduling rules. For a flow shop with two machines A and B where the jobs must be processed first on machine A and then on machine B, Johnson's rule minimizes the make span of the jobs. Make span is defined as the completion time of the last job in the schedule.

There has been extensive research in the area of stochastic scheduling with uncertain processing times of jobs. The priority rules for a single machine, deterministic processing times hold good for a single machine stochastic case too. For two machines and multiple jobs, the expected make span can be minimized by processing the jobs in the decreasing order of their expected processing times (Largest Processing Time - LPT). The proof of this theorem is due to Pinedo & Weiss (1979).

Scheduling rules of the above kind solve a single stand-alone problem. With time, these scheduling rules were not adequate for the complex manufacturing activities of huge factories. As the cost of computing has diminished with the advent of lightning-fast but inexpensive microprocessors, engineers demand the tools to integrate and control factory systems and resources.

1.5 Scheduling Systems

In most company's today scheduling is accomplished via a computer based system, rather than a series of independent problems. The two most popular systems that are used for Production Scheduling activity are - Material Requirements Planning (MRP) system and Shop Floor Control system based on Just-in-Time (JIT) philosophy. MRP was developed in the United States by Orlicky (1976), while JIT was developed by Ohno in Japan. Monden (1983) and the Toyota manufacturing industry pioneered the revolutionary JIT system (Sugimoro, 1977) which is very popular among Japanese companies and has been successfully utilized for their competitive advantage.

1.5.1 MRP-Based Scheduling Systems

MRP is a production and inventory control system designed to initiate procurement or production, on the basis of forecasted or scheduled demand for a product in a future period. The system uses the known dependency between the components that constitute the product, to explode product demand into demand for all intermediate assemblies and components. MRP attempts to provide the right part at the right time, i.e it aims at meeting the end item requirements of the Master Production Schedule (MPS). The major components of MRP are the MPS, Bill of Materials (BOM), inventory status file, the MRP processing logic and the management information from MRP.

The MPS is the driver to an MRP system. It receives all demands for the product, and translates these demands into planned orders to be used as inputs by the MRP logic. It is the model way in which the business will operate for a period. Normally, MPS provides a wider perspective on schedule activities over a long schedule time-line (for e.g., weekly or monthly view).

The BOM defines the relationship between an end item and its component parts and sub-assemblies, or between a sub-assembly and its component parts and sub-assemblies. The end items are called "parents" and the components and sub-assemblies used in their manufacture are called "children". A sub-assembly is a child to its parent end or parent subassembly and a parent to its child subassemblies and components. Each hierarchical parent-child relationship is a "level" in the bill. Information contained in the BOM file must include the parent part number, child part numbers, the quantity of each part required to make the parent and the date each child is to become effective or to be removed from use in the bill (effectively date control for scheduled engineering changes). Other elements may be present as well, such as shop floor delivery destination and engineering revision level.

Utilizing the MPS and the BOM, MRP can schedule and time phase the shop orders for all lower level items of each end product. The requirements of each product are known as the *gross requirements*. The inventory status file maintains uptodate information of the number of each product that is on inventory. This is known as the *on-hand*. Once the gross requirement, on-hand, and the lead time for each product is known, the net requirements for each product for each time period can be determined. Once the net requirements are known, the MRP processing logic determines the planned order releases for each component for each time period so that material arrives as and when required.

Planned order releases are the lead time off-set of the net requirements. The MRP output gives a report of all the above information in a tabular form which helps the management in giving advance notification to suppliers. These reports are updated at the end of each time period so that orders can be expedited or delayed as necessary. This information is very important when the product structure is complicated. These type of MRP systems are known as *Regenerative MRP systems*. In regenerative MRP all the previous planned order releases are deleted and the entire tableau is regenerated afresh. *Net Change MRP systems* are those systems where the previous planned receipts are added to the scheduled receipts, and the new tableau accounts for the new data only.

Once the MRP report is generated, a detailed capacity planning has to be done. This is very important in an MRP system since the reports are generated with the assumptions of infinite capacity. The major advantage of an MRP system is its rapid adaptability to dynamic changes and the ability to know what is required several periods in advance. The major limitation is that the entire system is to be computerized. The data must be accurate and the product structure must be assembly-oriented although MRP systems can be modified for process industries.

Thus an MRP system is independent of other corporate functions/systems. With a view to integrate MRP with the various departments like sales, purchasing, manufacturing and finance, and to develop a closed loop structure, and coordinate the manufacturing activities according to the schedules and manufacturing capacity, the concept of Manufacturing Resources Planning (MRP II) was formally introduced by Wight (1984).

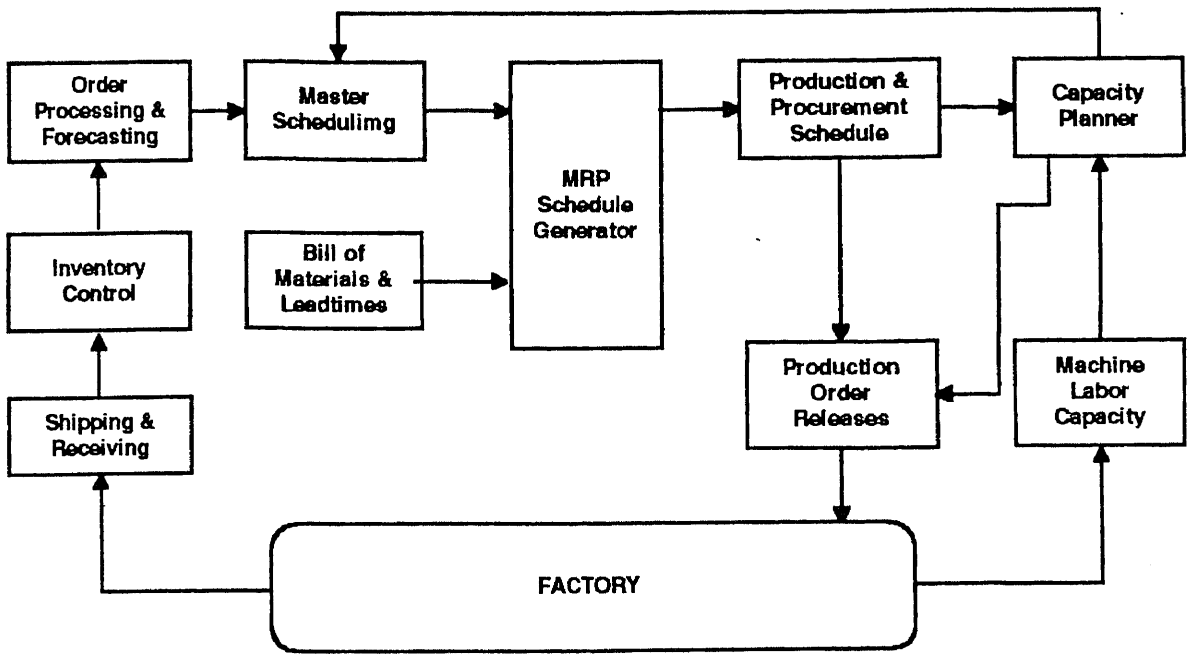


Figure 1: Illustrates the structure of MRP.
Source: Das S.K, "The JIT MRP and TQM Workbook"

PERIOD	1	2	3	4	5
Gross Reqmnts	12	46	22	2	42
Scheduled Receipts	3	6	8		
Net Requirements	9	40	14	2	42
Planned Receipts	0	35	15	0	45
Planned Ending Inv	6	1	2	0	3
Planned Order Rels	15	0	45	10	

Figure 2: An example of a MRP tableau of an product or item.
Source: Das S.K, "The JIT MRP and TQM Workbook"

MRP II has been a popular choice among companies in the United States to execute their PS&C activities. There are a large number of MRP II users and numerous software developers for MRP II application. The advantages of MRP II are well heralded by its practitioners. The logic behind the working of MRP is very simple and easily comprehensible. The strength of the MRP II systems lies in its planning capabilities. The user has a good overview of the production activity in the planning horizon. With MRP, the commitments over a period of time is known which helps in planning. MRP II also indicates which components need to be inventoried and when. Many firms claim as much as 40 percent reduction in inventory investment by using an MRP II system (Chase & Aquilano, 1989). The use of MRP II advocates disciplined and organized data handling procedures due to extensive computational requirements. This helps in achieving data integrity. MRP II is a "closed loop" system which helps in linking the production activity with the sales, purchasing and accounting departments. This helps in achieving better control over the different activities in the firm. MRP systems react well to changing conditions. They are particularly beneficial in such environments. Changes in the customer demands as reflected in the master production schedule can be translated into revised production and procurement plans by a single MRP run. This can be a cumbersome process for a large product without MRP.

1.5.2 JIT/Kanban Based Scheduling Systems

JIT system is a production management and control system designed to provide or deliver the right material at the right place in right quantities needed by "subsequent" production processes at the right time so as to minimize work-in-process (WIP) inventory. It also aims at coordinating the final assembly with the customer demand so as to minimize finished goods inventory. This technique was pioneered at the

Toyota Motor Company in Japan. The system hinges closely on a sub-system called Kanban. The Kanban production scheduling system is the most important part of JIT.

1.5.3 Hybrid Scheduling Systems

Hybrid systems use MRP techniques to develop a material acquisition plan under the infinite loading philosophy. After the initial plan is complete a finite loading process is applied to schedule the daily activity in the plant. Some of these systems are designed from the start to work this way and are available from the primary vendor; others are added on packages that can be interfaced to one or more standard MRP offerings.

To implement the finite load process, the user supplies a set of operations rules that allow the system to prioritize the load to identify which orders stay and which have to go. Length of production shifts, or over-runs are examples of such rules. Another set of parameters is provided by the user that the system will use to solve the problem. Examples of these parameters are: typical order size for a product or the minimum batch size dictated by the process, or the highest priority customer order.

The basic approach begins with the assignment of priorities, usually based on the MRP-derived due dates and traditional prioritizing methods. Other priority considerations might relate to the purpose of the job, for example , orders that are part of the requirements for a customer order might take priority over orders for stock. The finite scheduler then applies the work to the facilities in priority sequence. When the facility's capacity is committed, the rules are brought to bear on the problem. In some systems, the load is developed in the infinite manner, then the situation is displayed with a recommended solution (based on the rules) provided. The user approves or changes the solution using on-screen displays. Others present several possible solutions and ask the user to choose the "best" one.

Many of these infinite loading/finite scheduling hybrids provide slick color graphic displays of schedule and load information which assist the user in the approval/simulation process. Some finite loading modules provide traceability among parts that are all headed for the same end product. This is especially important if a number of independent activities are all tied to one end item and one of them is delayed. It makes no sense to expedite nine parts through the process if they will only have to wait at the final assembly stage for the completion of the tenth part which was delayed by a machine breakdown or material shortage. By recognizing the interrelationship between jobs (parts) using the actual BOM for the order, the system can coordinate all of the sub tasks to product completion.

The hybrid approach provides the benefits of both methods. Traditionally, MRP is used to plan the acquisition of materials, set of general parameters of the production schedule, and identify using Capacity Requirements Planning (CRP) potential future mismatches between load and capacity. The finite scheduling logic supports the short term objectives of establishing the best sequence and managing the flow on a daily basis, recommending solutions based on user-defined priorities.

Not every industry need the finite scheduling logic. If the production process involves a number of steps and extends days or weeks into the future, traditional CRP and shop floor infinite scheduling are usually fine. If customer commitments are made with only a very few days turnaround, or if the full loading of resources each day with a variety of short term requirements is the key to the business, then finite loading might be of great interest.

In the last few years there has been a thrust in the area of developing a PS&C system which is a combination of MRP & JIT systems. Both MRP & JIT are efficient systems to control the flow of parts, tools, information and material on the factory floor but a hybrid systems is reckoned to be more advantageous than the two independent systems. Promoting the growing consensus on the hybrid's viability is the premise that the push type production scheduling in MRP and the pull type scheduling in JIT/Kanban can co-exist in a single scheduling methodology.

In general, for production processes which are dedicated to one or a few similar products and where the production is continuous and level and the production lead times are predictable and uniform, kanban is the system of choice for material provisioning, order release, and shop floor management. At the other extreme where the product is low-volume, complex engineered, or custom manufactured with no regularity in production patterns, MRP II for materials planning, order scheduling for order release, and shop floor control system for shop management is the system of choice. However, most products and production systems fall between the two extremes, and generally the production control system of choice should be a hybrid that integrates the strength of both approaches. An example of a hybrid system is one which uses MRP scheduling techniques for material planning but a JIT system for order release and for controlling the work flow on the manufacturing line.

1.6 Problem Description:

MRP systems have been used to generate production schedules for jobs in many a manufacturing shop. However, the schedules have been found to be inaccurate and often not reflecting the realities of the day-to-day shop floor activities.

There are basically two problems with MRP-based schedules; these concern first the MRP logic itself, and second the fixed lead time assumption.

MRP logic: MRP systems perform their planning and scheduling function based on the assumption that machines and other resources have infinite capacities. This simple assumption leads to many unrealistic and infeasible plans and schedules. The infinite capacity assumption forces procurement of the materials earlier than is actually needed and sets unrealistic due dates. MRP's best tool against missing due dates is to "expedite." But by the time the MRP output is probed to find out what needs to be expedited, we have very few choices left and the chances are that we are already late.

A more recent generation of MRP systems-manufacturing resource planning (MRP II) with a simulation kit have tried to overcome this problem by enabling the user to visualize where the overloading problems are. Based on this information, the user is expected to re configure the schedule so that a feasible solution results. As it can be imagined, the reconfiguration task is not easy. Moving one or more orders may lead to many undesired side-effects, such as missing due dates, increasing setup times, and under utilizing some machines.

To make the problem even more complicated, consider all the other resources that need to be checked for availability. Such resources may include operators, molds, fixtures and materials. The MRP systems have little to offer in terms of monitoring, checking and allocation of such resources. The burden is therefore passed to the users of the system, who must constantly adjust the output to produce feasible schedules.

Fixed Lead Time Assumption: Another inherent problem of an MRP system is that its planning logic is based on fixed lead times as the work-in-progress level is increased. Regardless of the current work-in-progress levels and the current product mix, the MRP logic assumes fixed and predefined lead times for all the orders. It is possible to constantly change the lead times in the MRP system. However this is not a pragmatic proposition.

The objective of this project is to develop a PC-based Integrated MRP and Finite Scheduling System (MFSS) that derives daily job schedules for an example manufacturing shop.

Problem Environment: The shop manufactures a wide variety of components which are used in the assembly of several products. In addition to the assembly lines located in the same facility, the shop also supplies some components to facilities at other locations. Presently, the shop has multiple production machines to manufacture the various components, and utilizes many tools/dies to produce a variety of component parts. The same tool may be used to fabricate many different components by adding attachments, or introducing color changes, or other material composition changes. Each time the tool is to be setup in a machine it involves the removal of the current tool, the installation of the new tool, and the to and fro transportation of tools from a tool repository. Each time the raw material is changed, it involves preparing the machine and the raw material. Clearly, the tool setups and material changes severely effect the utilization of the machines, and decline in shop productivity.

The MFSS will provide the daily schedules for the manufacturing shop utilizing Net Change MRP logic and Finite Scheduling algorithms on product demand orders obtained from the shop's parent company. The MFSS will be run once at the beginning of each week.

1.7 Problem Statement

This thesis concerns the development of MFSS utilizing finite scheduling and sequencing algorithms and net change MRP logic to derive job schedules for a manufacturing shop. The input to the MFSS is the updated weekly MRP demand data (a five-week window of demand data) for the said facility. The output of the MFSS is the detailed daily production schedule for each production machine.

In developing the daily schedule, the objectives of the MFSS are to:

1. increase the utilization of each machine (i.e., increasing machine working time and reducing setup changes),
2. ensure that all planned deliveries be met, and
3. minimize the stock-piling of finished components inventory.

1.8 Research Objectives

To develop the MFSS the following three tasks need to be formulated:

1. Document the "as-is" scheduling procedure for this shop in order to establish the assumptions to develop the MFSS algorithm(s).
2. Design the automated scheduling system or MFSS, which involves the following steps:
    - deriving the weekly production quantities;
    - creating the Job ID(s) and setting the requirements date;
    - creating strings of jobs with common materials and tools;
    - sequentially assigning Job ID(s) to machines.
3. Develop a Personal Computer (PC) based MFSS software package to prove the viability of the MFSS approach.

CHAPTER 2

LITERATURE REVIEW

2.1 Prominent Scheduling Methodologies

The last decade has seen the ascent of newer PS&C techniques developed to solve the scheduling problems, such as Hierarchical Production Planning (HPP), Material Requirements Planning (MRP), Just-In-Time (JIT) and Optimized Production Technology (OPT). Several of the technique attempt to utilize the processing efficiencies of computer to make and distribute scheduling decisions.

2.2 Material Requirements Planning (MRP) Review

MRP was developed by Dr. Joe Orlicky in the United States (1976). He developed an independent / dependent demand principle. The principle is to forecast end product sales and use order point methodology to control finished goods replenishment now. The calculations, and component and raw material needs should be based on the plan to manufacture finished goods. Netting logic will manage these components and raw material inventories. Many inventory control practitioners rejected the move to MRP and most upper level managers were not aware of its existence. The American Production and Inventory Control Society (APICS) launched the MRP crusade, which was spearheaded by the three fathers of MRP namely Joe Orlicky, George Plossl and Oliver Wight and supported by many others. The result of this campaign was that MRP was being touted as the panacea for all manufacturing's ills. This was the start of MRP, if some what naive.

The term MRP was modified to Manufacturing Resources Planning (MRP II), an expansion to all the elements of a complete manufacturing control system. MRP II created a real breakthrough. The complete spectrum of manufacturing planning and scheduling was organized in a cohesive systematic way. Now, one could see how all the techniques fitted together and what their inputs, outputs and prerequisites were. The role of each management department and level of management also became clear.

MRP systems are computational tools and not sophisticated decision making procedure, but are a framework for providing useful information for decision makers. It is a backward scheduling process where in the activities are set up according to their requirement dates, working back in time from planned availability for shipment of the end item, through the BOM, identifying the dates to start acquisition in order to have the parts available when required. The result is planned purchases and production activities, designed to meet the demand and avoid shortage s. MRP is basically a "pull" type of a system because components are pulled in to satisfy a need..

MRP II was introduced in the mid 1970's and was heralded as the approach that would enable Western manufacturers to attain and maintain world class status. Oliver Wight called MRP II the method for "unlocking America's productivity potential." The only basic difference between MRP and MRP II are in the capacity requirements and shop floor control. MRP II is a closed loop system that integrates the different.

MRP is basically broken down into 4 steps:

1. Bill of Materials
2. Netting
3. Order Sizing
4. Planned acquisition quantity and due date.

In the first step of MRP the system starts with the master scheduled item in the first MRP level and uses the BOM to identify the components required. It is assumed that all components are required at the start of the production process, unless otherwise indicated. Most systems provide for an override to the production lead time for components not needed at the start of the production. The first MRP step is called "*post to component*", "*BOM explosion*", or "*gross requirements*". Its effectiveness is based on the accuracy of the BOM definition.

The second step is called "*netting*". It is to check the availability of the components to identify any net requirements or shortages. The current on-hand quantity, less expected usage, plus expected receipts between today and the date of need is compared to the required quantity. If sufficient stock will be available, the process is complete for that component. This is a time-sensitive process. The system must identify the expected usage and receipts between the present date and the date of need. These include existing acquisition activities, allocations for existing needs such as production orders already released and customer order backlog, plus activities previously planned but not yet released.

To identify all of the planned activities, the system must gather all requirements for an item from all sources before checking against availability. When BOMs are entered to the system, the computer will determine a "low-level code" which indicates the lowest level on any bill at which this item resides. Requirements are generated down to that level before netting can take place. Effective netting relies on inventory balances. The dates and quantities of expected receipts and usage must be accurately represented for the plan to be useful. Also during this step the system will attempt to satisfy any identified shortages by recommending changes to existing acquisition activities. Usually the recommendations will be to expedite if there is an expected shortage but an order exists with a later due date. An acquisition that is expected when there is no shortage will be flagged for deferral to a later date. On-order quantities not needed at all will be flagged for cancellation.

The third step applies to *order sizing logic* to determine the most effective quantity to make or buy. There are several lot-sizing techniques that can be applied. The most common are lot for lot which orders exactly what we want, fixed quantity where one always order X at a time, days of supply which is ordering whatever one needs for a fixed period of time and part period balancing (EOQ) which compares the higher carrying costs resulting from larger orders against increased ordering costs for smaller, more frequent orders. Most systems also provide for minimum, maximum and multiple overrides that are applied after any other lot size calculations.

The fourth step is the *planned acquisition quantity* and the *due date*. The only remaining piece of information to be determined is the date to release the purchase or production order or schedule. The start date is obtained in this final step of the MRP process, by subtracting the item's lead time from the due date. The lead time can be both fixed and variable elements and must be specified as the time required to acquire the item. It should recognize only the valid work days. One of the main assumptions against MRP is the assumption of a standard lead time. The lead time is not constant. It varies from season and also from vendor to vendor..

2.3 Just-in-Time (JIT) and Kanban Methodology Review

The origins of JIT is uncertain however it traces its beginnings to the Mitsubishi Heavy Industries shipyard in Hiroshima in the late 1950's. The Toyota Motor Company is credited for the first successful application of a formalized approach to JIT manufacturing. In 1969, Shigeo Shingo helped reduce the setup times from 90 minutes to 3 minutes. The philosophy behind the reduced setup times was adapted throughout the auto manufactures operations and led to the Toyota production system. In 1977 the concept of JIT was evolved into a formal PS&C methodology by the work of Taichi Ohno again of the Toyota Motor Company (Sugimoro 1977).

JIT system is a production management and control system designed to provide or deliver the right material at the right place in right quantities needed by "subsequent" production processes at the right time so as to minimize work-in-process (WIP) inventory. JIT is a pull type of production system. In this type of a system the more advance stage of production draws just the right amount of inventory from the preceding process in order to keep moving. This process continues right down to the raw-material stage or down to the parts or subassembly delivery stage. It also aims at coordinating the final assembly with the customer demand so as to minimize finished goods inventory.

The Japanese have been able to accomplish the JIT production system through a sub-system called Kanban. The Kanban is basically a production management information system through which the pull system of production control is accomplished. A detailed treatment of the functioning of Toyota's Kanban system can be found in the works of Krajewski and Ritzman (1987) .

Kanban is the Japanese word for tag or card. Kanban is a production management information system through which the pull system of production control is accomplished. It is used for linking two sequential centers in a production process. Every card carries a single piece of information - the need for a particular part. They can be literally cards or visible electronic signals in practice. It is much like having a product requisition system between each pair of centers but without all the paper work. It is also referred to as "zero inventories", "material as needed", "stockless production" and "continuous flow production". There are basically two types of cards; the withdrawal or conveyance, and production cards. Each Kanban specifies the name and number of the product, the lot size of the product and other required information.

JIT/Kanban methodology is the best known system for shop floor control. Many of the Japanese companies attribute the bulk of their present competitive advantage to JIT manufacturing. The philosophy of JIT inventory and manufacturing combined with the Kanban-based shop floor control has enabled many companies to phenomenally reduce their inventories. The major advantage of JIT/Kanban systems is its effectiveness in shop floor control and most uncertainties in planning and scheduling occur in the shop floor. The Kanban production systems require limited data handling and paperwork in the shop floor which makes them more popular among shop floor personnel.

JIT/Kanban systems help in reducing the inventory to a great extent. MRP systems tend to control the throughput and measure work-in-process (WIP) inventory while Kanban systems do just the opposite. They set the WIP inventory level and measure the throughput. The latter is better because WIP inventory is more visible and easily manageable.

JIT/Kanban systems are superior to MRP systems in their ability to point out quality problems quickly. Items are moved through the system is small batches in a Kanban system. This provides for efficient lot tracking and also makes 1OO% inspection feasible. Hence it is easier to incorporate JIT into an overall quality control strategy like Total Quality Control (TQC).

JIT systems maintain a few good vendors. This helps in maintaining a good rapport with them and also in achieving good quality of bought-out items. Since Kanban systems are pull systems, they can meet demand more realistically than MRP systems. This helps them to have an improved relationship with the customers.

On the basis of experiences in the U.S. and Japan, Goodrich (1989) states that JIT and MRP can work together, and that several Japanese companies are already using MRP II and JIT/Kanban together. Williams (1986) echoes the same opinion. He quotes Battles of Deere Industries, who says "we see MRP II as the master scheduler for planning purposes, and JIT as the execution of that plan". Williams recommends that MRP II systems be enhanced to incorporate JIT principles. Several studies in the direction of combining MRP II and JIT/Kanban have been reported in literature. These include the studies of Spearman et al (1989) who have developed the CONWIP (CONstant Work-In-Progress) method which is a modified Kanban system and that of Hodgson and Wang (1991a,b) who propose an optimal hybrid strategy for a multistage system. Most other research in this direction are also very narrow and do not address the entire PS&C function. There have been individual efforts like in the Unisys' Rancho Santa Margarita plant (Krepchin, 1988) to implement JIT/Kanban like system with MRP in a working plant.

2.4 Hierarchical Production Planning (HPP) Review

HPP, proposed by Hax & Meal (1980), is an aggregation scheme of items (final products) of an industry to families and types. Families are groups of items that share a common manufacturing setup cost and types are natural groupings of families. Using HPP with one of several disagregation techniques is a good strategy but does not necessarily work in every situation.

Anthony (1965) provided a framework to classify the decision support system which can be used for production control. He identified three levels of decision making: strategic, tactical and operational. Based on this framework, Hax and Meal (1975) championed HPP. HPP involves aggregation of products for aggregate planning as well as the subsequent disagregation of aggregate plans into detailed master schedules.

HPP divides the production planning problem into four distinct categories, one of which includes long-term manufacturing strategy. Three other categories are:

- Items : Final products to be delivered to the customer.
- Families: Group of items that share a common manufacturing setup cost.
- Types : Groups of families whose production quantities are to be determined by a single aggregate production plan.

The aggregate production problem is initially solved and then two subsequent disaggregations are to be done to obtain the Master Production Schedule. Several disaggregation procedures have been described in literature. Graves (1982) used Lagrangian techniques to derive the Hax-Meal hierarchy as a natural decomposition of a primal optimization problem. The Hax-Meal aggregation is not universally applicable but should match the manufacturer's organizational structure and product line. The advantage of HPP is that it is a finite scheduler and considers capacity constraints. The major problem with HPP is that it overlaps many production planning steps like long-term capacity planning, master scheduling, short-term capacity planning but cannot be implemented independently. Meal et.al. (1987) have proposed integrating HPP with MRP and use MRP to generate the master schedule and HPP as the capacity planning module.

2.5 Optimized Production Technology (OPT) Review

OPT, a proprietary product of Creative Output of Milford, Connecticut works on an algorithm developed by Goldratt (Meleton, 1986). The OPT system focuses on production bottlenecks on the shop floor. A potential delay at a work-center delays an entire production line or shift. The bottlenecks at the work-centers can be foreseen or predicted using network analysis and computer simulation techniques. Then a production schedule whose primary objective is to keep the critical work-centers free of potential bottlenecks is developed. OPT is not widely practiced and few of its users have reported impressive gains.

OPT is a system that schedules production off-line, like MRP but takes into consideration utilization's and resource dependencies. Its theory has depth but is still evolving. It claims to produce optimal schedules but the optimization criteria and the bottleneck scheduling algorithm are secret. OPT is a theory bundled with a software product.

OPT aims to produce schedules that are;

- Economic in the preceding sense;
- Realistic, in that they overload no resource;
- Safeguard against disruptions.

The OPT schedule is safeguard from disruptions in two ways:

- By specifying slack time at non-critical resources to ensure timely delivery;
- By maintaining an inventory buffer in front of critical resources to keep them busy.

It is an off-line system and as such it cannot respond to disruptions as they occur. It has no choice but to make allowances for the fact that they do happen. The OPT philosophy is based on the concept of "bottlenecks". The crux of OPT lies in identifying the bottleneck machines in production and scheduling so that there is no loss in production time at these machines. OPT adopts the network flow theory of max-flow min-cut in it's operation. It uses the fact that the total production rate of the facility is dependent upon or equal to the production rate of the slowest machines or the bottleneck machines. OPT also appreciates the problem in identifying the bottleneck machines in a facility which might be often a dynamic problem. Although bottleneck resources are different for different facilities,

OPT philosophy can be summarized by the following nine "rules" (Nahmias, 1989). Some of these rules may be viewed as "pearls of wisdom" while others are real theorems:

- Balance flow, not capacity.
- The level of utilization of the non bottleneck is determined not by its own potential, but by some other constraint in the system.
- Utilization and activation of a resource are not synonymous.
- An hour lost at a bottleneck is an hour lost for the total.
- An hour saved at a non bottleneck is a mirage.
- Bottlenecks govern both throughput and inventory in the system.
- The transfer batch might not, and many times should not, be equal to the process batch.
- The process batch should be variable, not fixed.

- Schedules should be established by looking at all of the constraints simultaneously. Lead times are the result of a schedule and cannot be predetermined.

2.6 Combined MRP II and JIT/Kanban Implementation

It is also evident that MRP II has more features and advantages than JIT to qualify as an overall comprehensive PS&C system. JIT/Kanban, although an effective shop floor control methodology, lacks overall planning capabilities and cannot handle demand fluctuations. While a number of different production planning decisions are to be considered before the JIT/Kanban system is activated, MRP II integrates almost all production planning decisions in one system. The only major drawbacks in MRP II are its infinite loading procedure and lack of standardized shop floor control mechanism.

MRP II, in spite of some of its disadvantages, has been used by the US manufacturers to meet their PS&C needs. But in recent years, the Japanese manufacturing industry, with the help of JIT/Kanban system has scored a decisive victory over its US counterparts. There are companies in the US trying to use the JIT/Kanban system in their facilities. However, JIT/Kanban systems have their own inherent drawbacks. It has been realized by researchers and practitioners that each new PS&C method should be viewed as an addition to, rather than as a replacement for the existing method. Hence there is a big thrust towards developing a hybrid PS&C system of the two must successful methodologies. Most research and implementation is geared towards the replacement of MRP II with JIT and the scant research in the area of developing a hybrid system lacks overall objective. Nagendra (1993) is developing a formal generic model that will incorporate the existing features of MRP II and append some new techniques into a single robust model (termed MRP-3) which can be utilized by the industry. A key feature of MRP-3 will be its shop floor control extension to the corporate functions of MRP II. Ashton et al (1990) state that "in spite twenty years of trying, most plants with MRP.. are still plagued by part shortages that disrupt operations." The MRP-3 model seeks to resolve this problem. It is expected that the research will culminate in the development of a generic database schema to make the MRP-3 system software marketable to any manufacturing enterprise.

2.7 The Need for Hybrid Scheduling Systems

Despite its cost and difficulty of use, MRP based scheduling and its logic have become part of the management information systems in many manufacturing businesses. Today, business is markedly different, where customers demand shorter cycle times, improved responsiveness to "volatile" demands and better quality, but at a competitive price. The inventory accumulation approach will not be tolerated. The capacity approach derived from "pull-based" methodologies manages complexity by breaking the enterprise into parts but de coupling it with capacity. To work effectively, pull-based methods require resident capacity -- i.e.,capacity becomes available when needed. However, the high capital investment required for increasing the capacity dictates the need for high utilization of resources for a reasonable payback. Such a scenario does not provide the required resident capacity for pull methodologies. In response, manufacturers are moving from an inventory-intensive approach to a capacity-intensive approach. U.S. manufacturers have been looking at a new derivative of the MRP investments-- a hybrid approach.

Hybrid Approach: This approach is the result of methodologies that attempt to implement a pull strategy with high resource utilization. The approach often will require tools to aid in planning, controlling, and managing an enterprise that will likely exhibit "nervousness" or "brittleness". However, the rewards are substantial for those that effectively balance and execute a hybrid approach because they will gain a competitive edge in responsiveness, cycle times, quality and cost. This mode of operation demands rather flexible and short response times from the entire enterprise-marketing, sales, engineering, manufacturing, distribution and suppliers-to ensure demand volatility can be met effectively. This calls for tools to help manage the increasing complexity of the entire enterprise.

Ken Sharma (1993) proposes methods to add "intelligence" to current MRP systems for improving the production scheduling and control activities. He examines the short comings of MRP systems and offers solutions to some of the inherent problems that MRP alone cannot address:

- the sequentially decomposed approach to planning and execution, and consequently, the time to execute an MRP cycle;
- the failure to recognize constraints, the assumptions of fixed lead times and the batching logic.

"Net change" and "turbo-MRP" solve the speed of processing changing requirements to make operations more "agile". However, they cannot address the other problems inherent in the architecture of MRP systems. The ability to see the impact of changes in demand, resources and material on local and global performance of the enterprise without having to re-run the MRP system represents a tough challenge. The dynamics of the floor have to do with factors such as frequency and duration of break-downs, size and frequency of demand changes, material shortages, rework, cancellations, etc. In most manufacturing environments, these factors tend to play a major role in the performance of the enterprise. In such cases, the capacity optimized planning and scheduling module in addition to MRP logic can have a significant impact on the performance.

Paul Roder (1993) describes an approach of implementing cost-effective Finite Scheduling modules to the existing MRP systems, and how the users can gain control of the manufacturing activities. By adding scheduling software, companies are able to enhance their systems without the problems of selecting and implementing a new integrated package. The return on investment is impressive. Finite scheduling can provide job shops and process manufacturers with the detailed information they have always asked and the results that management expects.

2.8 Summary

Production planning and scheduling activity will inevitably gain even more importance because it offers a clear competitive edge. It is important to realize production planning and scheduling is not concerned only with planning day-to-day or month-to-month activities on the shop floor. Production planning has a major impact on logistics, marketing, purchasing, quality and materials management. The new hybrid planning and scheduling system approaches offer new dimensions of control to managers, shop floor supervisors, operators, vendors, and customers. With such systems, hourly and daily updates on individual orders are possible, as well as the ability to examine within minutes the impact of new marketing demands on the plant. It is important to realize that while MRP systems have served many useful purposes, they are based on technology of the late 1960s and 1970s. MRP can continue to provide many useful functions if used judiciously and in cooperation with systems that address MRP's weaknesses and limitations. We live in an increasingly demanding environment, and the companies that recognize and implement the correct methodologies, tools and capabilities will succeed.

CHAPTER 3

DEVELOPMENT OF THE ALGORITHM

3.1 The Need for Production Scheduling and Control System

PS&C systems are concerned with planning for the use of productive resources to satisfy projected demand, and then scheduling the production processes so that the plan is effectively carried out. The length of time considered in developing the production plan is called the planning horizon. The resources of production to be scheduled are a combination of labor, processes/equipment, and raw material.

Determining an optimal production plan will involve solving a variety of significant subproblems: forecasting the demand for the products to be manufactured and the points in time at which they are required, and the production facilities to be employed. Control of the production process will involve periodic updating of the plan to account for errors in demand forecast, raw material availability's, or other changing conditions. In an increasing number of situations, management is relying on the computer to the solution of these problems.

The most important task in designing any production schedule and control system is to ensure that the plans and guidelines from higher levels guide do not unduly restrict , decision making at lower levels. Also feedback information on the actual conditions and performance must flow upward through the system to ensure that long-term plans are adjusted based on a realistic assessment of the current resource availability and the ability to produce.

Production managers spend most of their time in a continuous search for information. In the face of a stream of demanding problems calling for immediate attention and decisions, and chaotic nature of workflow, production managers often find themselves caught by an endless sequence of routine decision making. However in recent times, many production managers have changed the way they manage. They have begun utilizing new PS&C systems. Though these systems do not eliminate all of the crisis, they do point the way to a better control with less management involvement at the detail level.

3.2 Objectives of the Integrated MRP and Finite Scheduling System (MFSS)

The objective of this project is to develop a PC-based Integrated MRP and Finite Scheduling System (MFSS) that derives daily job schedules for a manufacturing shop. The shop manufactures a wide variety of components which are used in the assembly of several products. In addition to the assembly lines located in the same facility, the shop also supplies some components to facilities at other locations. Presently, the shop has multiple production machines to manufacture the various components, and utilizes many tools/dies to produce a variety of component parts. The same tool may be used to fabricate many different components by adding attachments, or introducing color changes, or other material composition changes. Each time the tool is to be setup in a machine it involves the removal of the current tool, the installation of the new tool, and the to and fro transportation of tools from a tool repository. Each time the raw material is changed, it involves preparing the machine and the raw material. Clearly, the tool setups and material changes severely effect the utilization of the machines, and decline in shop productivity.

The MFSS will provide the daily schedules for the manufacturing shop utilizing Net Change MRP logic and Finite Scheduling algorithms on product demand orders obtained from the shop's parent company. The MFSS will be run once at the beginning of each week.

The architecture of the shop scheduling (MFSS) procedure is outlined below.

The input to the MFSS is the weekly MRP demand data for the Manufacturing plant. The output of the MFSS is the detailed daily production schedule of each machine. In developing the daily schedule the objectives of the MFSS are to:

- increase the utilization of each machine (i.e., reduce number of setups),
- ensure that all scheduled commitments would be met, and
- minimize the inventory of finished components.

The MFSS will automate the scheduling of the manufacturing shop. In order to accomplish the above objectives the following three tasks are formulated:

1. Describe the current operations, procedures, and constraints of the shop.
2. Develop the algorithms for the automated scheduling system -- MFSS.
3. Develop a a preliminary software package on a PC to demonstrate the viability of the new system.

In the following sections we describe the results of each task. In the last section, subsequent tasks or potential next steps for this project are outlined.

3.3 Description of the Tasks And Development of the Algorithms

3.3.1 Description of the Manufacturing Shop Operations.

The current procedure is summarized in Figure 3. The shop is divided into three separate sub-shops on the basis of the shop various operations. Each sub-shop produces an exclusive set of products. A product can be manufactured on any machine in the sub-shop, though some assignment preferences may exist. The scheduling process for each sub-shop, while independent of each other, is identical in structure. Each sub-shop is managed by a scheduler, whose primary function is to receive the weekly MRP demand data from the corporate system, and generate a detailed schedule. We label the generated schedule as planned control. In addition to the planned control, the scheduler also executes some dynamic control. On average 3 to 5% of the production has to be rescheduled, due to schedule changes in the main plant.

The MRP demand data specifies the demand for the current period, plus four subsequent periods (weeks). Thus the demand for each week can change up to four times after its original specification. The shop is equipped with a schedule and control system, that operates on a PC network. Each subshop scheduler builds the schedule on this system. There are three steps under planned control (P1, P2, P3 - see Figure 3). The key decisions made by the scheduler are:

- whether to produce a batch of a particular product,
- how much to produce,
- what is the requirements date,
- which machine should it be assigned to, and
- in what sequence.

While the objective is to ensure that all demand is met, the decisions are made on the basis of the subject matter experts in the shop.

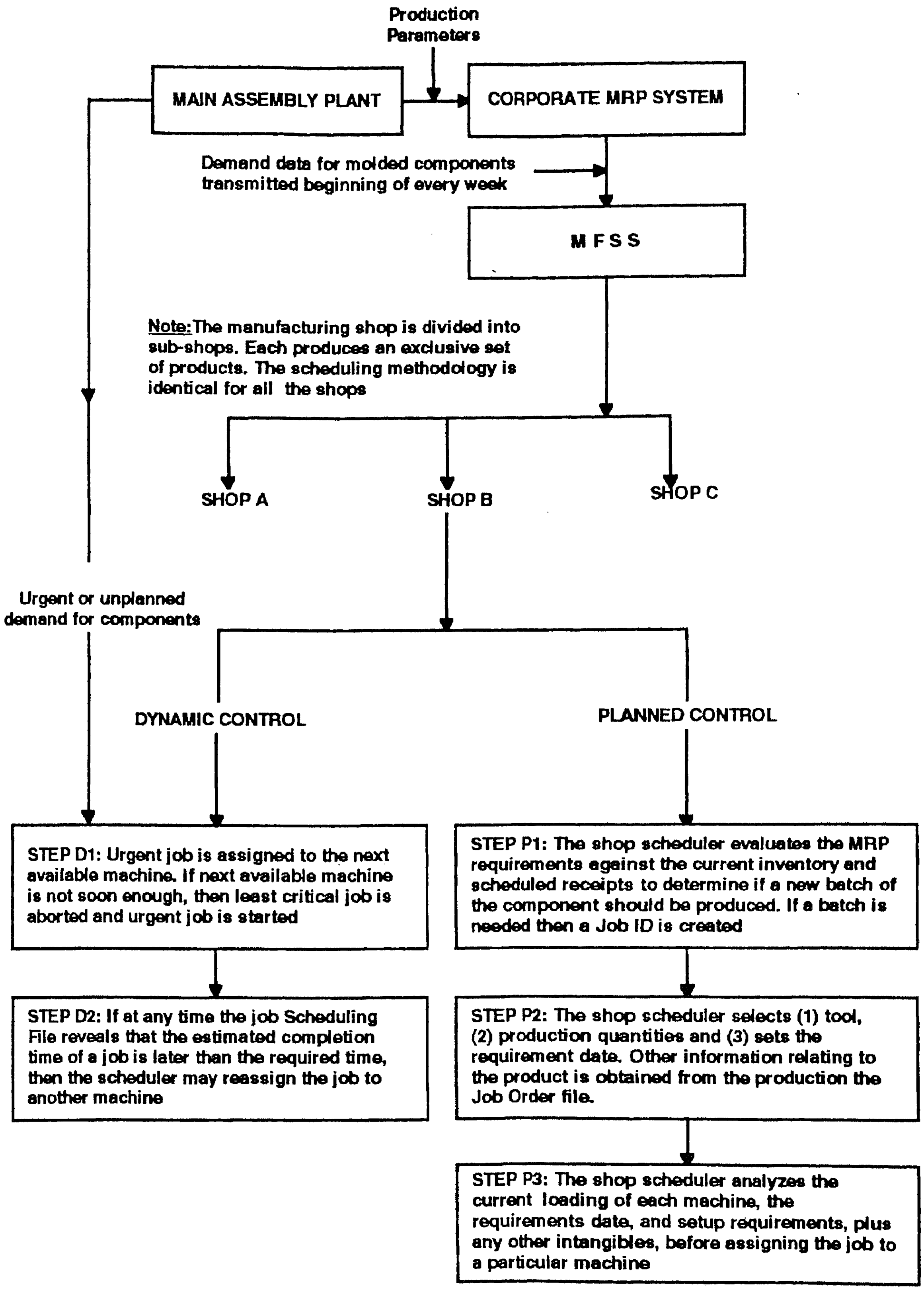


Figure 3: Overview of the Schedule Operations of the Manufacturing Shop

3.3.2 Design the New Automated Scheduling System

The specific goal in designing an automated procedure that replaces the manual scheduling function done by the shop scheduler. The automated MFSS procedure would generate the five decisions identified above. Furthermore, the procedure would increase the utilization rate of the machines, hence enabling the shop to operate with fewer machines in the future than today.

In designing the MFSS we need to minimize the formatting differences between the new scheduling system and existing shop procedures. The proposed MFSS procedure consists of four algorithms which are sequentially executed. The procedure is run once at the start of each week, after the weekly Demand Requirements data is received from the Corporate MRP system. In designing the procedure and the individual algorithms certain key assumptions and concepts are formulated based on the scheduling objectives and long term goals of the shop.

The assumptions and concepts are elaborated below:

1. It is assumed that the MRP data specifies requirements are delivered latest by the end of the week.
2. The standard cycle time for the majority of components is less than 60 seconds. In theory, all the components could be produced in the week of requirement. Consequently the shop would operate in a semi-JIT environment, and there would be minimal inventory.
3. There are two reasons why this ideal may not be attained. First, there is setup time (typically a 2 hour activity) associated with each component. Second, since the number of components manufactured is quite large and demand is not steady, capacity problems can arise.
4. Setup involves two tasks, changing the tool/die, and changing the material. Setup times vary from 1 hour up to 3 hours, and account for significant machine

downtime. Often two products will have a common material or die, in which case the schedule must attempt to exploit this condition by assigning the two products to the same machine.

5. Since the setup time is relatively long, each product has a specified minimum economic production quantity or batch size (B). Thus it will be necessary to produce more than the requirement, and maintain the excess in inventory. Further, it is always economical to produce at most only one batch of each component per week.

6. Though the MRP provides demand data for the next five weeks, we are really concerned with the production scenarios for the present. Technically, an extended MRP forecast is most valuable when there are multiple stages of production and/or several raw materials are procured. In this case, we assume only a single production stage (such as Injection Molding Process, or Tire Manufacturing). Further, most of the raw material is procured in bulk and thus stocked. There are two benefits of the extended demand in this case. First, to determine if future weekly demand is expected to be so great that it cannot feasibly be produced in one week, then we would have to produce some components in earlier periods and maintain inventory. Second, since there is a minimum batch size restriction the question is whether current production quantities can also be increased to meet the demand of future periods. Based on the above assumptions and concepts, the four algorithm architecture has been developed. In the following subsections, the purpose and detailed design of each algorithm is presented. The operational and programming details of each algorithm accompany the presentation.

3.3.2.1 Algorithm #1: Deriving the Weekly Production quantities

- Derives the weekly production quantities for each component during the next five weeks (note; weeks are numbered as 0,1,2,3, and 4). The production quantity is also the production batch size for the component.
- To minimize the effect of change, the production quantities for weeks 0 and 1 are revised from the earlier planned quantities, while, those for weeks 2,3, and 4 are regenerated.
- The algorithm progresses from week 0 to 4. For each week the algorithm calculates the net demand (N), which is defined as the MRP demand minus the starting inventory. If $N >= B$, then the production quantity (X) is set to N. If $N < B$, then an additional evaluation is done. When N is small then it may make sense to add it to the previous weeks production, or alternatively if there is no production in the previous week, then in the week prior to that. In the extreme case demand for the next four weeks could be produced in a single case. Define D as the critical demand quantity. Algorithmically the decision is made as follows, if $N <= D$, then for $i=1$ to 3 where i denotes the number of weeks early, if $N/(1+O.2(i-1)) <= D$ and production is presently scheduled in the earlier week, then N is added to that weeks production. There are therefore two design parameters in the algorithm, B and D. Both must be appropriately designed.

Listing of Algorithm #1 - Deriving the Weekly Production Quantities

ENTER NEW DATA FROM CORPORATE MRP

Product ID (i): A229

Week (T) t	04-II 0	04-III 1	04-IV 2	05-I 3	05-II 4
Proj Reqmnt	39	53	52	50	53
Prev Reqmnt	30	62	52	50	41
Net Change	9	-9	0	0	12

Calculate Production Quantities for t=0 & 1

Calculate based on net change, and starting inventories

T=Current period #
For t=0,1
    For i=1 to P
        If $N_{i,t}>0$ then $X_{i,t}=\mathrm{Max}[X_{i,t}+N_{i,t}, B_i]$,
            else if $X_{i,t}=\mathrm{Max}[X_{i,t}-N_{i,t}, B_i]$
        End if
        $I_{i,0}= X_{i,0} + I_{i,-1} - C_{i,0}$
    End i loop
End t loop

Calculate Production Quantities for t=2,3, & 4

For t=2 to 4
    For i=1 to P
        If $C_{i,t}-I_{i,t-1}\leq 0$ then $X_{i,t}=0$,
            else if $C_{i,t}-I_{i,t-1}\leq D_i$ and $X_{i,t-1}>0$ then
                $X_{i,t-1}=X_{i,t-1}+(C_{i,t}-I_{i,t-1})$ and $I_{i,t-1}= C_{i,t}$
            else if $C_{i,t}-I_{i,t-1}>D_i$ then
                $X_{i,t}=\mathrm{Max}[B_i, C_{i,t}-I_{i,t-1}]$ and $I_{i,t}= X_{i,t}+ I_{i,t-1} - C_{i,t}$
        End if
    End i loop
End t loop

3.3.2.2 Algorithm #2 - Creating the Job I.D.'s and Setting the Requirements Date

- In the current system, production is executed in batches which are identified by Job IDs. The Job ID contains several pieces of information, key among these are: Product ID, Production Quanity, Tool ID, Material ID, Required Date, Machine ID, Start Time, Processing Time. The Product ID identifies the component to be manufactured, based on which the Tool ID, material ID, and processing time are retrieved from the system database. The remaining four entries are decisions which are generated. Production Quantity has already been specified in Algorithm #1. Note that in some cases the system provides multiple tool choices for a component, we shall assume by default the system selects the best available tool.
- In this algorithm a Job ID is automatically created for each component for which there is a demand in weeks 0, 1, and 2. Again we are really interested only in jobs to be produced in the current week, the only reason we are looking at weeks 1 and 2 is to see if there are any capacity problems downstream. The Job IDs for weeks 1 and 2 are thus temporary and will be purged at the start of the next week.
- Though we assume that the weekly requirements are to be delivered at the end of the week, we shall attempt to prioritize which components are manufactured early in the week, and which later. The reason for this is should the plant schedule move-up the mold shop will be in a position to supply the requirements.
- Each week is divided into three requirement intervals, end of Tuesday (R1), end of Thursday (R2), and end of Friday (R3). Depending on the production quantity and the starting inventory, the Job ID is assigned one of the three requirements date. The logic is as follows. If the starting inventory (I) is zero and $N >= B$, then the date is R1, or else if $N < B$, then the date is R2, and finally if the starting inventory is greater than zero then the date is R3.

Listing of Algorithm #2 - Creating Job ID's & Setting the Requirements Date

TRANSFER CONTROL FROM STEP-1 ALOGRITHM

↓

Creating the Job I.D. & Setting the Requirements Date

Purge all previously created Job I.D.'s with a start date during period 0. N= Job ID of last job remaining in list.

Job I.D.'s are generated sequentially by a system function and have no special interpretation.

Each Job ID is denoted by:

JID(N, [ ])=JID(N, [prod ID, qty, tool #, matl #, Reqd time, mach #, proc time, start time])

```
t=0
R1=36, R2=72, and R3=90
For i=1,P ------ Line #### 0
    If X_{i,0}>0 then N=N+1
        If I_{i,t}=0 then ReqdTime=R1
            Else if X_{i,t}≤1.2B_i then ReqdTime=R2
            Else ReqdTime=R3
        End if
        proc time = U_i + X_{i,t}Y_i
        JID(N,[ ])=N, [i, X_{i,t}, i(tool), i(matl), ReqdTime,-,
        proc time,-]
    End if
    End i loop
If t=0 then
    t=1, R1=126, R2=162, and R3=180
    GoTo Line ##0
End if
```

note: i(tool) and i(matl) are retrived from the database. Further, a "-" indicates there is no entry or the previous entry is left unchanged.

3.3.2.3 Algorithm #3: Creating Strings of Jobs With Common Materials and Tools

- This algorithm identifies strings of related Job IDs. Within a string for each pair of consecutive Job IDs either the tool, material, or both are common. Since the objective is to minimize the number of material changes and tool changes, all Job IDs in the string are assigned to the same machine.
- The algorithm generates all possible strings, hence a Job ID may appear in more than one string. For each Job ID there will be a string in which it appears alone. The total time to process each string is calculated. The requirement date for the string as a group is set equal to the earliest requirement date within the group.

Listing of Algorithm #3 - Creating Strings of Common Job I.D.'s

TRANSFER CONTROL FROM STEP-2 ALOGRITHM

Creating strings of jobs with common materials and/or tools

{F1S,..,F1E} Set of job I.D.'s with reqd date in period t=0
{F2S,..,F2E} Set of job I.D.'s with reqd date in period t=0

Each string of jobs is represented by L(n,[ ]). Where, n, is the string #, L(n,1) is the number of jobs linked, L(n,2) to L(n,11) are the jobs stringed, L(n,12) indicates whether the string has ended, and finally L(n,13) is the earliest required date in the string.

```
f1 = F1S and f2 = F1E
For  f = f1 to f2 ----- Line ##1
    For  e = f1 to f2
        If JID(f,-,i(tool),-,-,-,-,-)= JID(e,-,i(tool),-,-,-,-,-)
            or JID(f,-,-,i(matl),-,-,-,-)= JID(e,-,-,i(matl1),-,-,-,-)
            then SIM(f,e)=1
        Else SIM(f,e)=0
    End e loop
End f loop
n=1
For  f = F0 to F1
    L(n,1)=1, L(n,2)=f, L(n,12)=0,  W=0, n^0=n and n~=n
    TIM(n) = JID(f, proc time) and L(n,13) = JID(f,Reqdtime)
    For q=1 to 10
        For n*= n to n^0 , and L(n*,12)=0
            V=0
            For  f*= f1 to f2, &  f*∉ L(n*,[ ])
                If SIM(L(n*,q), f*)=1 then
                    If V=0 then L(n*,1)=L(n*,1)+1,
                        L(n*,q+1)=f*, V=1, W=1
                        L(n,13) = Min(L(n,13), JID(f*,Reqdtime))
                        TIM(n*) = TIM(n*) + JID(f*, proc time)
                    Else L(n~,[ ])=L(n*,[ ]),
                        L(n~,q+1)=f*, n~=n~+1, W=1
                        L(n,13) = Min(L(n,13), JID(f*,Reqdtime))
                        TIM(n~) = TIM(n*) + JID(f*, proc time)
                End if
            End f* loop
            If V=0 then L(n*,12)=1
        End n* loop
        n^0=n~-1
        If W=0 then quit q loop
    End q loop
    n= n~
End f loop
If f1=F1S then, n^1=n-1, f1 = F2S and f2 = F2E, GoTo line ##1
Else n^2=n-1
```

3.3.2.4 Algorithm #4: Sequential Assignment of Job IDs to Machines

- This algorithm employs the principles of Longest Processing Time (LPT) assignment and the Least Machine Utilization (LMU) assignment to develop the machine schedule. These rules fit the best for a hybrid systems approach of balancing the view of MRP demand data and actual shop floor control (typically JIT).
- Starting from the first requirement date in week 0 to the last requirement date in week 2, the algorithm progressively assigns the Job IDs to the machines. The algorithm logic is as follows. From the candidate pool select the string with the largest numbers of Job IDs for assignment. If there is a tie in the number of Job IDs, then select the string with the longest processing time. Locate the machine with the least utilization. Then sequentially assign all Job IDs to that machines. Cancel all candidate strings, in which at least one Job ID has been assigned. Note that since originally all possible strings were generated, partial strings will still be in the candidate pool. Finally, update the machine utilization by the processing time of each Job ID. Simultaneously, calculate the start time of each Job ID.
- Check if for any week the machine utilization is greater than 100%. If yes then attempt to move production early, by utilizing the slack in earlier weeks. If insufficient slack is available, then move production back Recompute start times and update database. If for any component the demand can not be met, then alert factory management.
- At the end of this algorithm all the entries associated with the Job IDs have been generated, and the schedule can be implemented.

Listing of Algorithm #4 - Sequential Assignment of Job ID's to Machines

TRANSFER CONTROL FROM STEP-3 ALOGRITHM

↓

Assigning the Job I.D.'s to the Machines

```
{1,..,n^1}    Set of job strings created for period 0
{n^1+1,..,n^2}    Set of job strings created for period 2

t=0 and N*=0
For k = 1 to G
    UTIL(k) = US(k)
End k loop
n^0=1, n*=n^1, and N=n^1
For R^= R1, R2, R3 ----- Line ##2
    TMAX=LMAX=0, N*=N*+1, and n~=100 ----- Line ##3
    For n = n^0 to n*
        If L(n,1) ≥ LMAX , SIGN(n)=0 and L(n,13)=R^ then
            LMAX=L(n,1), SIGN(n~)=0, SIGN(n)=1 and n~=n
        Else if L(n,1) = LMAX then
            If TIM(n) ≥ TMAX, L(n,13)=R^, and SIGN(n)=0 then
            TMAX = TIM(n), SIGN(n~)=0, SIGN(n)=1, and n~=n
        End if
    End n loop
    TMIN=10000
    For k = 1 to G
        If UTIL(k) ≤ TMIN then
            TMIN = UTIL(k) and k^0=k
        End if
    End k loop
    r=SL(k^0)
    For b = 1 to L(n~,1)
        f*=L(n~,1+b)
        SEQ(k^0,r+b)=f*
        JID(f*, StartTime) = UTIL(k^0)
    End b loop
    UTIL(k^0) = UTIL(k^0)+TIM(n~)
    SL(k^0)=SL(k^0)+L(n~,1)
    If N*<N then GoTo line ##3
End R^ loop
If t=0 then
    t=1, n^0=n^1+1, n*=n^2 , N*=0, and N=n^2 - n^1
    For k=1 to G, UE(k)=UTIL(k) and SE(k)=SL(k), End k loop
    GoTo line ##2
Else
    For k=1 to G
        If UTIL(k)≤ 180 then LAG=180-UTIL(k)
            For f*=SEQ(k,SE(k)+1) to SEQ(k,SL(k))
                JID(f*,starttime)=JID(f*,starttime)+LAG
            End f* loop
        End if
    End k loop
End if
```

Variables:

- t = Weekly Period # (Period 0 being the current week)
- i = Specific Product
- $X_{i,t}$ = Job Production Quantity of Product i in Period t
- $C_{i,t}$ = Cumulative Requirements of Product i in Period t
- $I_{i,t}$ = Inventory of Product i at the end of Period t
- N = Job ID of last job order created
- $N_{i,0}$ and $N_{i,1}$ = Net Change $Product_i$ Requirements for Periods 0 & 1
- R_J = Required on Date J, where J=2,4,5 days OR 36,72,90 Hours (3 Shifts per day @ 6 Hours a Shift = 18 Hours per Production Day)
- B_i = Economic Batch Size for a Product (Minimum Feasible Quantity)
- D_i = Break-even Quantity OR Critical Demand Quantity
- U_i = Setup Time for Product i
- Y_i = Time to one unit of Product i

3.3.3 Create a Preliminary Software Package To Illustrate The New System

In an attempt to illustrate the working and feasibility of the proposed MFSS procedure, a sample software was developed. This software is built on a commercial database system, and designed to run in the PC Windows environment. The table on the following pages exhibit some of the output from the developed package. The only input to the software is the weekly demand, and the output is the Job IDs for the current week.

3.4 Summary and Next Steps

The feasibility of an automated scheduling system linking the mold shop operation with the corporate MRP demand data was illustrated in this project. The proposed MFSS procedure requires only a few additional data entries, beyond that which is currently used. The MFSS will generate all the outputs and schedules of the current system. Our initial tests indicate the MFSS will greatly increase the production capabilities of the shop, and significantly decrease inventory levels. The computational requirements of the MFSS are not severe, and as illustrated, can easily be implemented in a PC environment. We would recommend the following next steps in this project. First, to define the two key design parameters in the MFSS, the minimum batch size (B) and the critical demand quantity (D). This should done by analyzing historical demand patterns for each component and the associated setup times. The second step would be to develop a simulation model, with purpose of evaluating the performance of the new system. This evaluation would also provide an assessment of the minimum number of machines required to meet projected demand. Finally, the development of a software package to execute the algorithms and link with the current Job ID tracking system should be initiated.

CHAPTER 4

CREATING THE PERSONAL COMPUTER-BASED MFSS APPLICATION

In the development of finite capacity algorithms and net change MRP logic to derive the job schedules for the manufacturing shop, a relational database system has been employed. Traditionally, PS&C systems have been divided into 4 discrete stages: routing, scheduling, dispatching and expediting. Integrating the production control function and other manufacturing functions into one computer information system can be accomplished by a database management software system. A database can be viewed as an integration of application files. Relationships between the data records within one file and the data records between another file are precisely what a relational database management system (RDBMS) software can accomplish.

The RDBMS provides the capability to store data records and automatically create and maintain all the relationships that are required between data records. The RDBMS affords a controlled way of accessing and manipulating data to provide useful output that can be utilized for shop floor operations. The MFSS is built on the RDBMS foundation while integrating mathematical algorithms for MRP and Finite Scheduling with the RDBMS raw data to produce outputs in the form of Data Table, Form/Query View, or a Summary Report. The algorithms for MFSS have been written in a programming language that is provided with the RDBMS.

4.1 The Relational Database System (RDBMS) for MFSS

4.1.1 The Computer Hardware Platform

The MFSS has been developed and implemented on a Personal Computer (PC) . The PC's Intel 486-DX 33Mhz (megahertz speed) CPU (central processing unit) with 4 MB (megabytes) of RAM (random-access memory) provides respectable speed and flexibility to run a fairly large application such as MFSS. The computer system also consists of a 100 MB fixed disk (also called hard disk), 5.25" and 3.5" floppy disk drives, Super VGA Graphics color display, and a Microsoft-compatible Mouse.

4.1.2 The Computer Operating System

The operating system software used in the computer system described above is MS DOS 5.0 with Windows 3.1 software. The system can run all Windows-based applications in multi-tasking fashion allowing the user to share data between applications such as the word processor, spreadsheet, drawing, database, and communications. The speedy processor used in the computer provides all the necessary horse-power required by the applications software. MFSS inputs, logic, and outputs can be manipulated using many of the Windows-based applications.

4.1.3 The RDBMS Application Development Environment

The RDBMS selected to develop the MFSS is the relational database system for Windows called Microsoft Access version 1.0. The Microsoft Access software helps to organize data according to subject which makes it easy to track and verify, and store information about how different subjects are related, which can then be manipulated at any point in the application to bring the related data together.

To implement the MFSS using a RDBMS such as Microsoft Access would require an understanding of the Database design process. Good design ensures fast access to information and efficient handling of processes. The key is to understand how MFSS information are related to each other. Access stores the data as part of different subjects in separate Tables. For example, Product information is stored in Product Table, and Tool information is stored in Tool Table. To combine these facts in a meaningful manner Access needs to know how the subjects are associated with each other. For example every Product can be processed using one of multiple available Tools. Therefore Product need not store Tool information. Every Tool will have a corresponding Product that it identifies with. Hence Product, identified uniquely by Product ID, will be the relating data link between the Product and Tool Tables. In other words, Product ID is a Key field. All Tables will have one primary key field and one or more secondary key fields to package related information from multiple Tables together.

The following steps are used in the database design process:

- ***Step One: Start with a purpose:*** Determine the main purpose of the application to decide which facts have to be stored.
- ***Step Two: Determine the Tables:*** Divide all necessary facts into separate subjects such as "Process Master", "Product", "Tool", ...etc..
- ***Step Three: Determine the fields:*** Each of category of information is called a field and is displayed as a column in the Table. For example: one field in the Product Table is Material ID.
- ***Step Four: Determine the relationships:*** Observe each Table and decide how the data in one Table is related to the data in other Tables. Add such fields to clarify relationships, as necessary.
- ***Step Five: Refine the design:*** Analyze the database design for errors using sample data and make adjustments and data manipulations to the design as needed.

4.1.4 Integrated System Development Features Summary

Access allows the developer to create sophisticated, visual database applications.

- Graphical query by example enables one to create even the most complex queries visually -- simply "drag and drop" objects to join Tables and to specify fields for display.
- Visual form -- generation tools let one to choose fields from a list and then drag and drop them onto the form, One can also drag and drop Windows controls such as list boxes, check boxes and radio buttons.
- The banded, two pass report writer enables one to create richly formatted, presentation -- quality reports without writing code.

One can also use innovative tools to be more productive and automate routine tasks:

- Form Wizards and Report Wizards ask questions about format content and style and then automatically create the Form or Report. This enables the user to creatively enhance the information presentation over and above what the application provided the user.
- Macros make it easy to automate routine database management tasks.
- The RDBMS can directly read and write data in other popular database application formats. Thus information such as corporate MRP requirements developed by another system can share its data with the Access RDBMS as input to the MFSS application.
- The versatile architecture of the Access RDBMS can function as a stand alone database application, in a file-server configuration or as a front-end client in a client-server environment.
- Object linking and embedding (OLE) makes this system easy to create and edit databases, charts, and spreadsheet objects from within the RDBMS.
- Powerful programming environment: The RDBMS can be enriched with sophisticated visual functions that perform complex mathematical and logical

algorithms. This is possible through Access Basic, a fully extensible database programming language with integrated debugging tools and automatic context sensitive help and syntax checker, in addition to the benefit of incremental compilation. This reduces the development time drastically.

4.2 The MFSS Application Organization

4.2.1 Scheduling Application Feature Summary

The MFSS is a production scheduling application which assist the production planner or shop floor manager to create job orders for products and assign those jobs to the production machines for the current and next weekly periods. The timing of the jobs and the production quantities are derived by the MFSS algorithms which is detailed in Chapter 3.

Input requirements are provided to the system on a weekly basis from a corporate MRP system or office detailing the weekly product requirements for the current period and four subsequent weeks. The aim of the MFSS is to translate the requirements from this view into specific MRP-based weekly production quantities for the current and the next week (a two-week window). The MFSS then utilizes the shop loading algorithms to match job orders based on common raw materials and common tools to optimize the selection of machines to assign the jobs. It is expected that the MFSS has the potential to provide reliable and cost-effective schedules to manage the shop floor. The schedules assume that the economic batch sizes and the break-even job size for the various products are known to the MFSS. Also MFSS tries to achieve the maximum utilization of the machines in the shop.

4.2.2 MFSS User Operations Summary

The MFSS operations function from the following menu featured by the application: The main menu is illustrated in Figure 4

- ***Edit/View Data:*** When executed MFSS shows a sub menu with the following functions. The sub menu is illustrated in Figure 5

  Add New Product: When executed MFSS opens a Product Form to view current product records. The user can add a new product record on an empty form, and also edit existing product records.

  Add New Process: When executed MFSS opens a Process Form to view current process records. The user can add a new process record on an empty form, and also edit existing process records.

  Add New Tool: When executed MFSS opens a Tool Form to view current tool records. The user can add a new tool record on an empty form, and also edit existing tool records.

- ***Order Form:*** When executed MFSS opens an order requirements form to input the requirements for the current and the next four periods (weeks). The system automatically generates the dates for each week to be the Monday of that week. After the user inputs the requirements for each product for the five periods, the user confirms the data entry in the form by pressing the "Commit Orders" button. On closing the form, MFSS executes the net change MRP algorithms.

- ***Load From Data File:*** When executed MFSS reads data from a text file (reqts.dat) directly. Then the MFSS executes the net change MRP algorithms automatically. The data can be created using any text editor. It is in ASCII format. It contains the overall products requirements for the five periods starting with the current period. This loading occurs once every week.

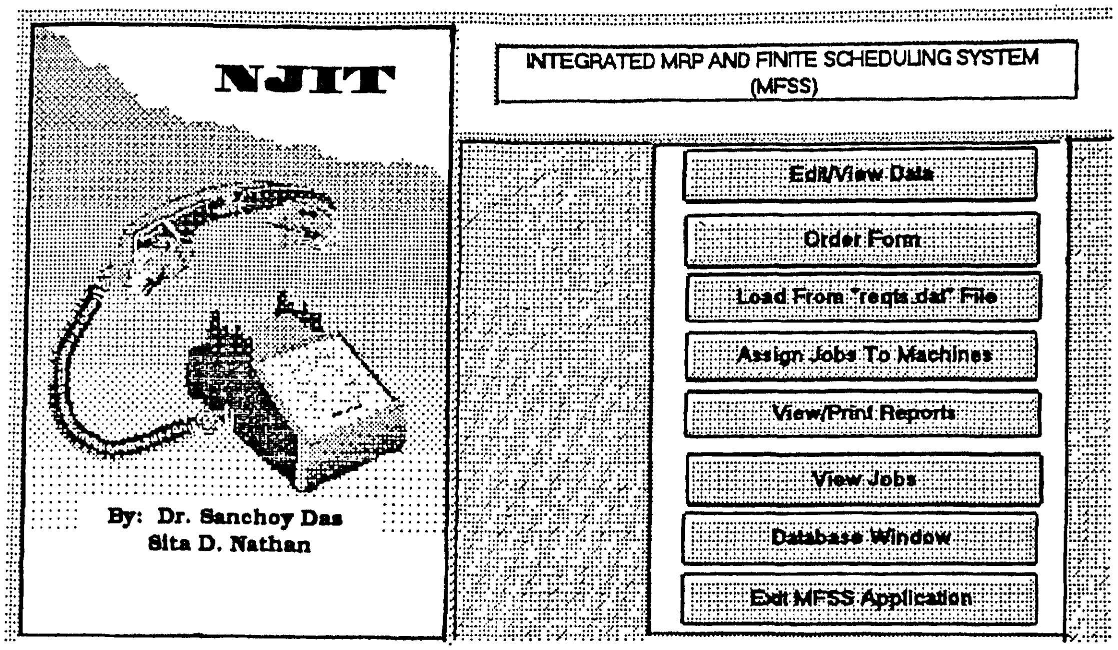


Figure 4: The Schematic View of the main menu

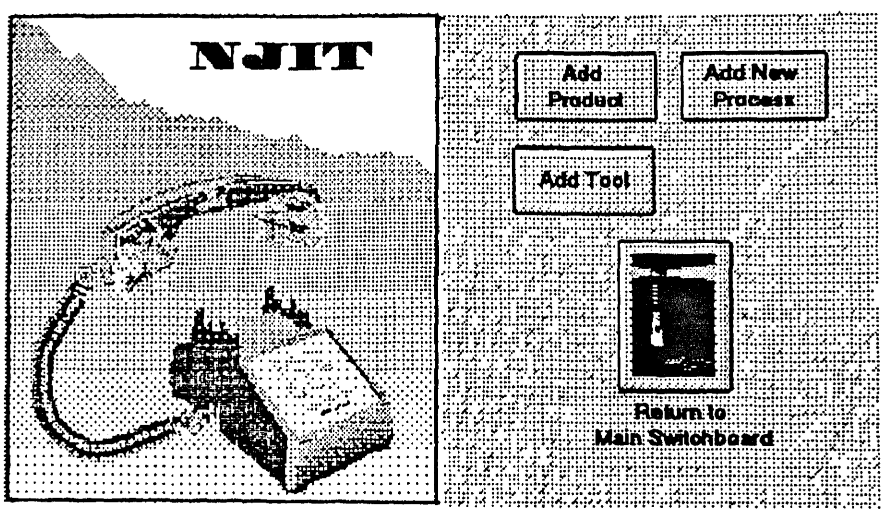


Figure 5: The Schematic View of the sub menu

- ***Assign Jobs To Machines:*** When executed MFSS executes the job assignment algorithm for all the jobs scheduled in the current and next period.
- ***View/Print Reports:*** When executed MFSS shows a sub menu with the following functions.

  MRP Report: The MRP algorithm generates the MRP report for each product. This function opens that MRP report for viewing.

  Job Summary Report: The Job assignment algorithm generates the job order summary report for each product scheduled for the current and next periods. This function opens that job order summary report for viewing.
- ***View Jobs:*** When executed MFSS shows a sub menu with the following functions.

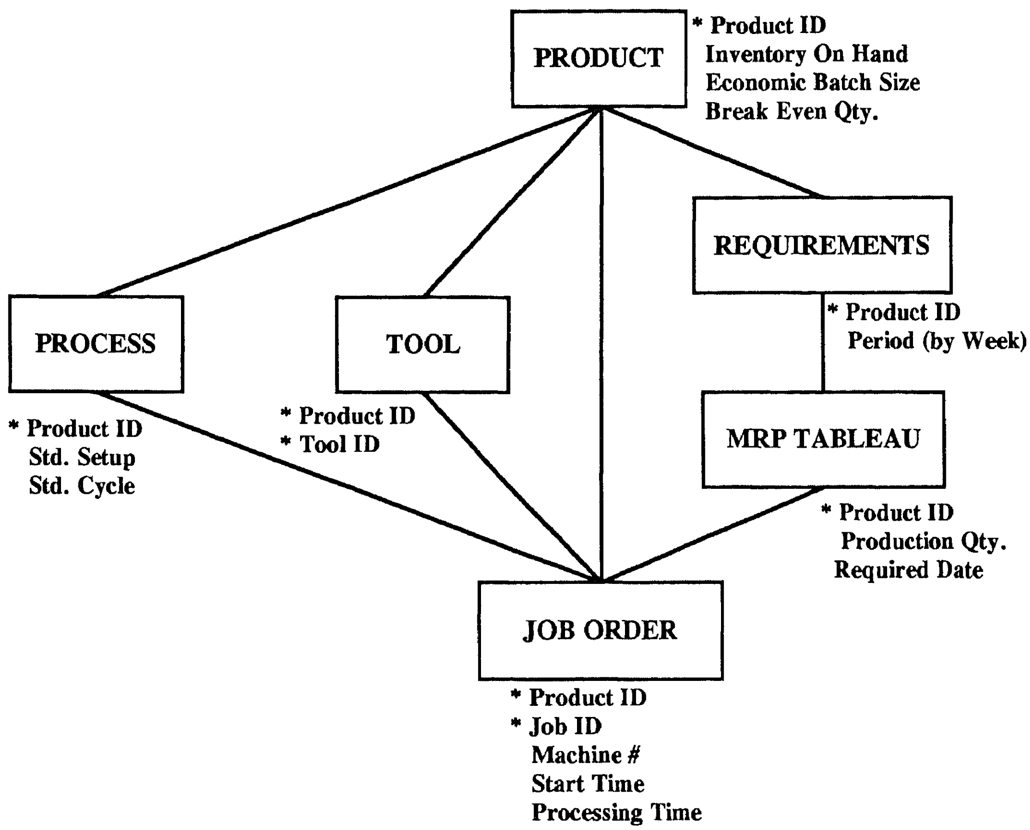
  Summary Job Orders: The Job assignment algorithm generates the job order summary for each product scheduled for the current and next periods. This function opens the job summary form for viewing.

  Jobs In Period 0: The Job assignment algorithm generates the job for the current period only. This function opens the jobs for the current period form for viewing.

  Jobs In Period 1: The Job assignment algorithm generates the job for the next period only. This function opens the jobs for the next period form for viewing.
- ***Database Window:*** When executed the user is put in the Microsoft Access database menu. This provides direct database access to the current application.
- ***Exit Application:*** Ends the MFSS application execution.

4.2.3 MFSS Database Architecture

The schematic view of the relationships of the MFSS objects is illustrated in Figure 4. The main MFSS objects are: Product, Process, Tool, Requirements, MRP Tableau and Job Order. There is a 1:1 relationship between a Product and a Process. A Product can use multiple Tools. A Product has a 1:1 relationship with Requirements, MRP Tableau, and Job Order. The key field linking the objects is the Product ID. Other specific key field are identified with an asterisk "*" in the Figure 4. A Job Order has an aggregate relationship with the Product, Process, Tool, and MRP Tableau. The relationships may be viewed as a "join" of the multiple tables.



INTEGRATED MRP AND FINITE SCHEDULING SYSTEM (MFSS) DATABASE HIERARCHY

Figure 6: The schematic view of the relationships of the MFSS objects

CHAPTER 5

TESTING THE MFSS APPLICATION

5.1 Testing the MFSS Modules

Multiple products, process parameters and tools were added prior to the System Test procedure outlined in this chapter. This was accomplished using the **Edit/View Data** option and selecting the appropriate forms for data entry namely:

- **Add Products**
- **Add Tools**
- **Add process parameters.**

The three forms used are illustrated in Figure 7 below.

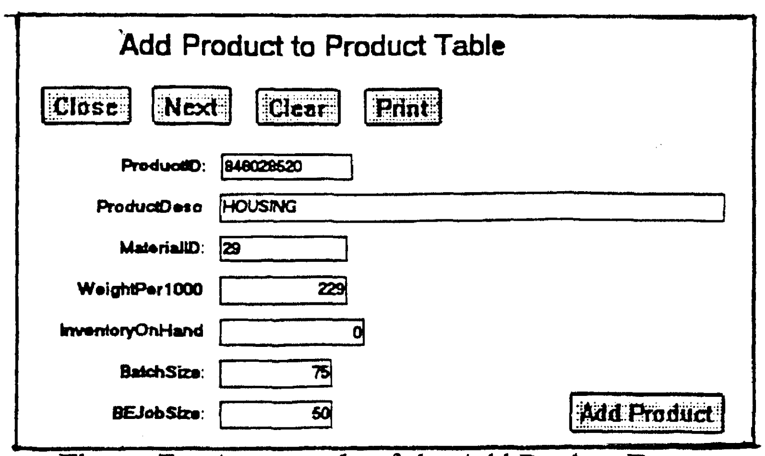


Figure 7a: An example of the Add Product Form

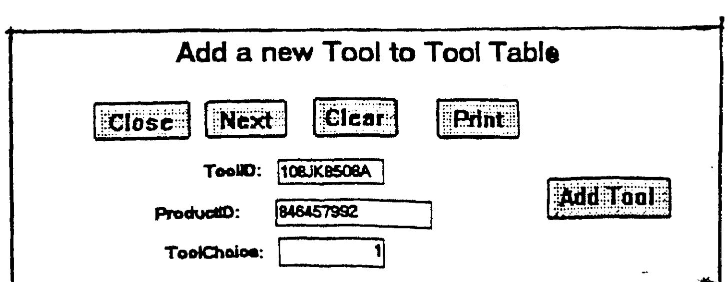


Figure 7b: An example of the Add Tool Form

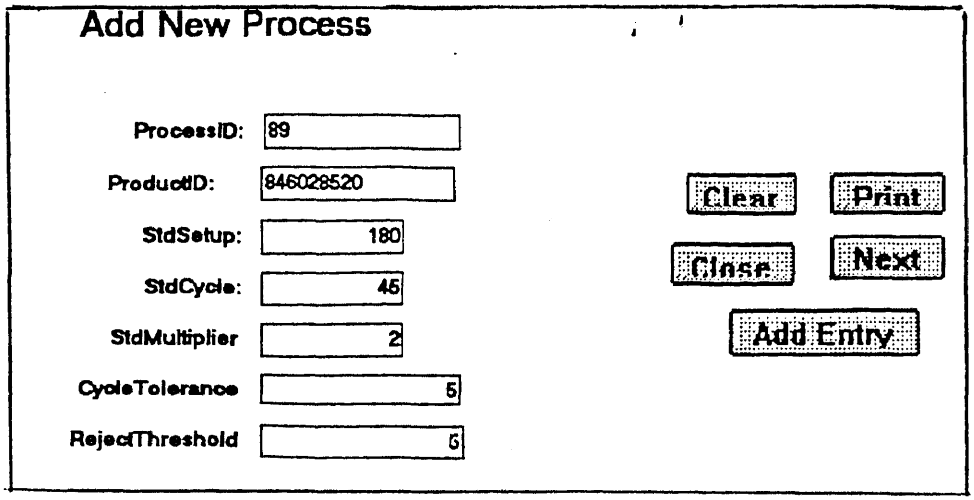


Figure 7c: An example of the Add Process Form

Open the Microsoft Access application under Windows 3.1 system. Open the MFSS application. From the Main Switchboard Form menu, the following steps are executed to test the system, and obtain the results for analysis.

5.1.1 Requirements Order Entry

Weekly Requirements Data entry can be done in one of the 2 ways explained below:

- **Form Entry**
- **Reading from a File**

Form Entry (Requirements Update Form) procedure is illustrated in Figure 8 below.

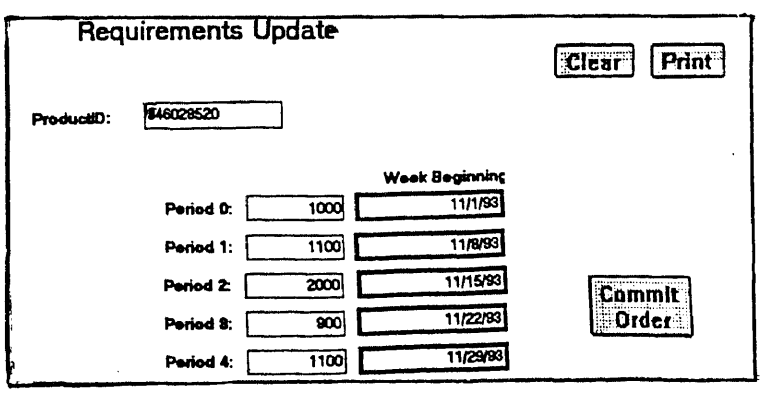


Figure 8: An example of the Requirements Update Form

The data file approach was utilized for the 8-products/14 week requirements model. The objective was to generate the job orders to produce the product and the schedule assignments of those jobs to the machines utilizing the MFSS algorithms (outlined in Chapter 3) built into the application.

Create "***reqts.dat***" data file using any text editor. Here, we are using Microsoft Write Editor. The file contains the Corporate MRP requirements for the 8-products to be manufactured in the shop. The requirements are for the next five weeks. This file changes in its contents week to week. The file format contains the Product ID to be produced and its current requirements for each product for periods 0 (current period) to period 4. The data entered must be separated by commas in the order shown;

ProductID, Reqt0, Reqt1, Reqt2, Reqt3, Reqt4

For eg: **846028520, 2000, 800, 910, 150, 200**

The "***reqts.dat***" for the 1st Week run appears similar in format to the values shown below:

846028520, 2000, 800, 910, 150, 200
846028530, 775, 675, 250, 600,400
846457992, 650, 400, 370, 200, 150
846458008, 900, 540, 540, 490, 206
846477792, 1100, 670, 800, 550, 430
846506657, 1775, 470, 830, 520, 400
846614790, 1000, 700, 975, 550, 475
846700359, 850, 550, 100, 650, 300

Select the **Load From "reqts.dat" File** button from the Main Switchboard Menu. This will read the requirements from the file in one shot.

5.1.2 Generate MRP Tableaus

The system generates the MRP Tableau for the requirements based on the Net Change MRP algorithm. An example MRP Tableau report is shown for a product in Figure 9. The production quantity determined for Periods 0 and 1 are the basis on which the job orders will be created.

MRP Tableau

ProductID:	846028520
InventoryOnHand:	0
BatchSize:	75
BEJobSize:	50

Week of:	11/1/93	11/8/93	11/15/93	11/22/93	11/29/93
New Reqts:	1000	950	1050	500	200
Old Reqts:					
Net Reqts:	1000	950			
Prod. Qty:	1000	950	1050	500	200
End of Wk In	0	0	0	0	0

Figure 9: An example of the MRP Tableau

5.1.3 Create Weekly Job Orders

The system also creates two sets of Job Order files with all the pertinent data regarding the product, process parameters, the tool, and production quantity:

- **Jobs In Period 0**
- **Jobs In Period 1**

To view the job lists select the button "**View Jobs**" and select the above mentioned job lists. It must be noted that these are only interim products. When the requirements are updated the succeeding week, they get emptied.

5.1.4 Assigning the Jobs to Machines

Select the button "**Assign Jobs To Machines**" from the Main Switchboard menu. The system immediately assemble all possible combinations of "string" of jobs for each of the machines, and test the combinations against the objectives of reduced processing time by minimizing setup time through the use of common tools and raw materials for various jobs on a given machine. The application then assigns the machines for the job orders scheduled for Periods 0 and 1. The "**Job Order**" selection under "View Jobs" menu item keeps a cumulative list of all the jobs generated without modifications throughout the system test procedure.

5.1.5 Viewing Schedule Results

Select "View/Print Reports" from the Main Switchboard menu. To view the scheduled Job Summary results, choose the "Jobs Summary Report". An example illustration of this report is displayed below in Figure 10.

JOB ORDER REPORT

Creation Date:	01-Nov-93
JobID:	10925
ProductID:	846028520
ToolID:	84SP0304A
StdSetup (Mins):	180
StdCycle (Secs):	45
StdMultiplier:	2
CycleTolerance (in %):	5
RejectThreshold (in %):	5
ProductionQty:	1000
Processing Time (Hrs):	9
RequiredDate:	11/2/93
Period:	T45t36
MaterialID:	29
WeightPer1000:	229
Starttime:	0
Machine:	10

Figure 10: An example of the Job Summary Report

The other schedule related output of interest is the Machine Output Schedule Table. This table identifies the job orders assigned to each of the machines by the MFSS, as a final schedule. The Machine Output Schedule Table snapshot is illustrated below in Figure 11.

	Machine Output Schedule								
Week	Machine	util	us	ue	se	sl	seq1	seq2	seq3
11/1/93	6	7	0	7	1	1	937		
	7	10	0	10	1	1	933		
	8	12	0	12	1	1	939		
	9	28	0	28	2	2	927	929	
	10	21	0	21	3	3	925	931	935
11/8/93	6	6	0	6	1	1	953		
	7	9	0	9	1	1	955		
	8	16	0	16	1	1	949		
	9	20	0	20	2	2	943	945	
	10	28	0	28	3	3	941	947	951

Figure 11: An example of the Machine Output Schedule

The schedule results for the fourteen consecutive weeks have been assembled in the form of Gantt charts. The Gantt charts, shown in Figures 10 and 11, illustrate the time-line view of job assignments on machine, thereby demonstrating the effective utilization of machines and the viability of the MFSS approach and application.

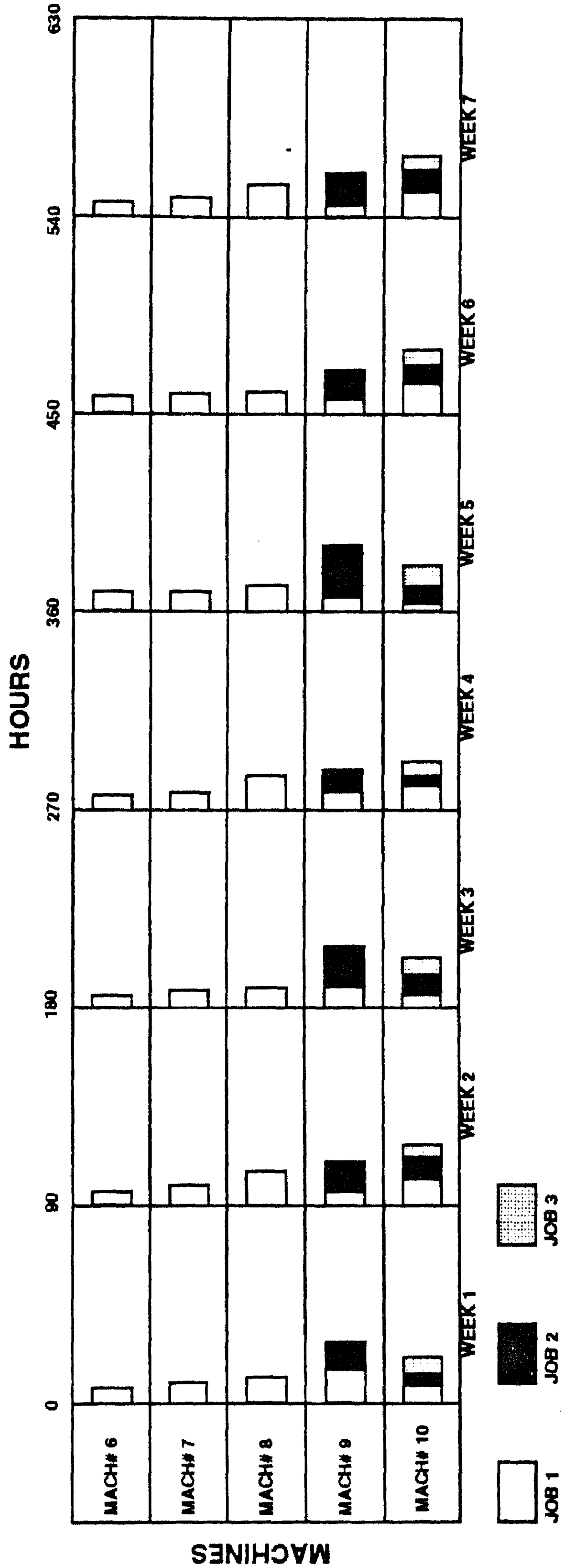


Figure 12: Gantt Chart Schedule of Jobs on Machines for the first seven weeks.

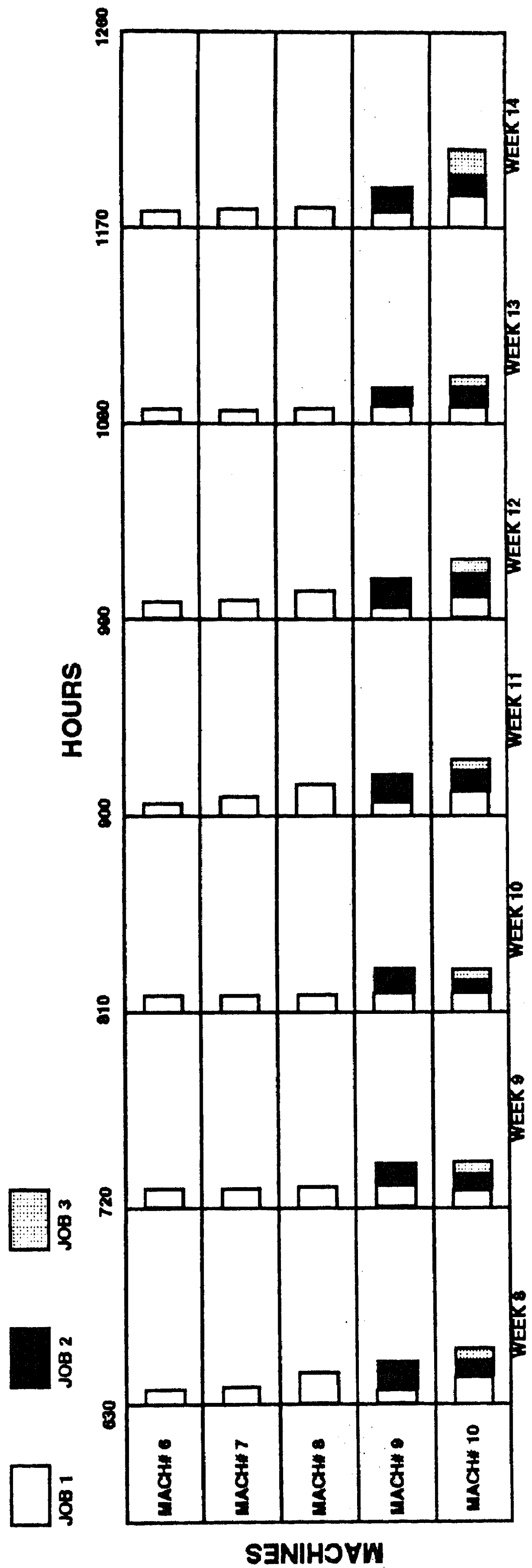


Figure 13: Gantt Chart Schedule of Jobs on Machines for the second seven weeks.

CHAPTER 6

CONCLUSIONS AND FUTURE ENHANCEMENTS

6.1 Conclusions

The feasibility of an automated scheduling system linking the shop floor operations with the corporate MRP demand data has been illustrated in this thesis. The MFSS will generate all the outputs and schedules that are currently being provided manually by a shop scheduler. Initial results indicate the MFSS will greatly increase the production capabilities of the shop, and significantly decrease inventory levels. The computational requirements of the MFSS are not severe even in a PC environment. The MFSS utilizes the shop's current design parameters: the minimum batch size (B) for a given product and the critical demand quantity (D) for the product as principal inputs to the MFSS.

There are certain cases where manufacturing operations are controlled by a sophisticated MRP II systems or MRP with JIT/Kanban systems. The scheduling functions check the shop's capacity to specify realistic shop schedules. There are a large number of companies today who have invested heavily in traditional MRP or MRP II systems. These companies are at the cross roads of decisions when they are finding out that JIT/Kanban culture as well as capital commitments are overwhelming for the size of their operations. Finite scheduling system vendors are fulfilling the needs of these companies by filling the void in the MRP systems with dynamic control modules that help the schedulers to visualize options. Based on this author's thesis, it can be concluded that these companies can pursue an integrated and customized MFSS solution to gain control and reliably schedule their manufacturing operations. The prototype of this work has been accepted as a scheduling system for AT&T's Shreveport (LA) factory operations. This leads the author to believe that MFSS like systems can be customized for large companies that prefer a decentralized or distributed scheduling and production control solutions.

6.2 Areas for Future Enhancements

It is an unfortunate reality that the scheduling of production is often an "upstairs" staff function, while the actual production is performed "downstairs" in a very dynamic real-time world. The theoretical schedules are created by finite or infinite assumptions based periodically on a snapshot "picture" of the factory status. However, after the loading schedule for the machine is developed using statistically correct algorithms at the global level, the reality of the factory floor presents some deterministic hurdles which often render the schedule useless.

Factory management is faced daily with the problems which occur in an uncertain environment. Motors burn out, tooling wears out or breaks prematurely, employees don't show up, tooling or stock fails to arrive on the receiving dock, or someone forgets to charge the forklift batteries over the weekend. A dynamic visual simulation module can increase an individual's ability to fine-tune the scheduling process in those critical situations. Such a system will promote consensus among the various shop personnel by involving them in the scheduling decisions. The system must combine the planning and schedule priorities at the business level and the factory level with the aid of a computer simulation model that can test the MFSS's schedules and provide detailed short-interval schedules which reflect the factory realities. Interactive decision-support aids for reviewing and ranking alternative schedules would make the scheduling system even more powerful. Further, implementation of such systems on relatively low-cost distributed microcomputers enhance their attractiveness to the human scheduler -- the essential element required to close the loop between systems and actual operations.

The following two steps are recommended to enhance the MFSS in the near future:

1. Provide a built-in tool in MFSS to analyze the historical demand patterns for each component and the associated setup times, in order to establish the production parameters B and D as a replacement to the shop's parameters. This will make the MFSS product more general-purpose and re-usable in other manufacturing shop scheduling applications.
2. Develop a simulation model to evaluate the shop performance utilizing the MFSS output schedules in order to fine-tune the final schedule before releasing it to the shop floor. This evaluation would also provide an assessment of the minimum number of machines required to meet projected demand. This approach can mitigate the impact of unanticipated changes during the work week, such as: machine breakdowns, preventive maintenance schedules, and changes to the shop resources like materials, labor, materials handling, and tools. The MFSS can further be improved by providing interfaces to real-time shop floor systems such as the automatic identification systems (for example: barcodes) for the shopfloor which track labor operations, and job's movement and status in the shop.

APPENDIX 1

REQUIREMENTS FILE

The requirements were inputed in a data file and read by the program by clicking on the "reqts.dat" file button. The data is organized as follows. The format contains the Product ID and its requirements for periods 0 to 4. The data is seperated by commas as shown below.

Date

ProductID, Reqt0, Reqt1, Reqt2, Reqt3, Reqt4

For eg: **846028520, 1000, 950, 1050, 500, 200**

REQUIREMENTS FROM THE CORPORATE MRP

11-01-93
846028520, 1000, 950, 1050, 500, 200
846028530, 2000, 1250, 550, 300, 600
846457992, 700, 750, 400, 290, 100
846458008, 100, 250, 300, 300, 200
846477792, 1100, 670, 800, 550, 430
846506657, 775, 950, 530, 200, 400
846614790, 670, 1000, 550, 475, 850
846700359, 1500, 975, 1000, 750, 865

11-08-93
846028520, 1500, 810, 675, 600, 900
846028530, 400, 1750, 550, 775, 100
846457992, 890, 550, 875, 675, 500
846458008, 1050, 650, 650, 890, 400
846477792, 2000, 870, 300, 450, 970
846506657, 475, 950, 900, 300, 550
846614790, 540, 600, 850, 100, 200
846700359, 960, 975, 700, 960, 150

11-15-93
846028520, 500, 450, 800, 200, 100
846028530, 760, 850, 750, 530, 300
846457992, 1250, 650, 900, 700, 600
846458008, 1000, 375, 550, 775, 520
846477792, 1000, 950, 530, 200, 200
846506657, 775, 950, 530, 200, 400
846614790, 370, 800, 760, 500, 675
846700359, 875, 400, 100, 665, 725

11-22-93
846028520, 1400, 1000, 940, 600, 850
846028530, 775, 950, 530, 200, 400
846457992, 560, 800, 978, 350, 200
846458008, 100, 250, 300, 300, 200
846477792, 670, 1000, 490, 200, 100
846506657, 540, 870, 400, 450, 250
846614790, 750, 400, 290, 100, 50
846700359, 2000, 1005, 800, 740, 300

REQUIREMENTS FROM THE CORPORATE MRP (continued)

11-29-93

846028520, 156, 570, 100, 400, 100
846028530, 600, 450, 550, 675, 200
846457992, 1700, 850, 700, 190, 400
846458008, 775, 900, 500, 600, 100
846477792, 990, 790, 865, 650, 230
846506657, 1150, 1250, 550, 475, 850
846614790, 1000, 750, 865, 300, 300
846700359, 1500, 975, 530, 200, 400

12-06-93

846028520, 1700, 850, 700, 190, 400
846028530, 670, 1000, 550, 475, 850
846457992, 775, 900, 500, 600, 100
846458008, 990, 790, 865, 650, 230
846477792, 1100, 670, 800, 550, 430
846506657, 775, 950, 530, 200, 400
846614790, 690, 780, 660, 500, 400
846700359, 900, 875, 650, 200, 275

12-13-93

846028520, 1500, 810, 675, 600, 900
846028530, 400, 1750, 550, 775, 100
846457992, 890, 550, 875, 675, 500
846458008, 1050, 650, 650, 890, 400
846477792, 2000, 870, 300, 450, 970
846506657, 475, 950, 900, 300, 550
846614790, 540, 600, 850, 100, 200
846700359, 960, 975, 700, 960, 150

12-20-93

846028520, 1750, 875, 900, 800, 550
846028530, 650, 675, 875, 800, 700
846457992, 500, 400, 100, 100, 400
846458008, 590, 680, 700, 775, 500
846477792, 1000, 900, 800, 600, 400
846506657, 400, 600, 400, 500, 500
846614790, 880, 970, 900, 775, 700
846700359, 670, 650, 700, 570, 500

REQUIREMENTS FROM THE CORPORATE MRP (continued)

12-27-93
846028520, 990, 790, 700, 600, 100
846028530, 1500, 750, 350, 575, 550
846457992, 600, 600, 650, 500, 550
846458008, 575, 150, 450, 270, 150
846477792, 900, 670, 980, 300, 130
846506657, 530, 200, 400, 550, 475
846614790, 775, 950, 100, 500, 850
846700359, 1100, 670, 290, 750, 865

01-03-94
846028520, 890, 550, 400, 560, 750
846028530, 980, 400, 600, 755, 500
846457992, 800, 880, 650, 750, 550
846458008, 400, 150, 450, 270, 150
846477792, 875, 920, 400, 250, 190
846506657, 530, 670, 290, 750, 865
846614790, 880, 600, 750, 300, 850
846700359, 750, 950, 100, 500, 530

01-10-94
846028520, 1500, 810, 675, 600, 900
846028530, 400, 1750, 550, 775, 100
846457992, 890, 550, 875, 675, 500
846458008, 1050, 650, 650, 890, 400
846477792, 2000, 870, 300, 450, 970
846506657, 475, 950, 900, 300, 550
846614790, 540, 600, 850, 100, 200
846700359, 960, 975, 700, 960, 150

01-17-94
846028520, 1500, 810, 675, 600, 900
846028530, 400, 1750, 550, 775, 100
846457992, 890, 550, 875, 675, 500
846458008, 1050, 650, 650, 890, 400
846477792, 2000, 870, 300, 450, 970
846506657, 475, 950, 900, 300, 550
846614790, 540, 600, 850, 100, 200
846700359, 960, 975, 700, 960, 150

REQUIREMENTS FROM THE CORPORATE MRP (continued)

01-24-94

846028520,	750,	775,	950,	400,	650
846028530,	1000,	100,	800,	865,	600
846457992,	1100,	670,	550,	475,	850
846458008,	900,	550,	900,	800,	100
846477792,	700,	1050,	500,	590,	500
846506657,	300,	670,	1000,	100,	100
846614790,	550,	475,	850,	300,	200
846700359,	400,	475,	100,	650,	85

01-31-94

846028520,	2000,	800,	910,	150,	200
846028530,	775,	675,	250,	600,	400
846457992,	650,	400,	370,	200,	150
846458008,	900,	540,	540,	490,	206
846477792,	1100,	670,	800,	550,	430
846506657,	1775,	470,	830,	520,	400
846614790,	1000,	700,	975,	550,	475
846700359,	850,	550,	100,	650,	300

02-07-94

846028520,	600,	800,	650,	400,	175
846028530,	1450,	755,	450,	870,	100
846457992,	900,	555,	650,	350,	100
846458008,	500,	650,	750,	450,	300
846477792,	760,	860,	760,	400,	200
846506657,	1775,	1050,	975,	720,	250
846614790,	1000,	700,	650,	850,	750
846700359,	1550,	975,	850,	300,	200

APPENDIX 2

OUTPUT OF THE JOB SUMMARY

The program generates the output for the jobs scheduled for the fourteen weeks. The following process parameters is constant.

Product ID	Material ID	Std Setup (mins)	Std Cycle (secs)	Std Multiplier	Cycle Tolerance (%)	Reject Threshold (%)	Weight Per 1000
846028520	29	180	45	2	5	5	229
846028530	50	180	45	2	5	5	100
846457792	50	180	45	1	5	5	300
846458008	36	180	45	2	5	5	250
846477792	56	180	45	2	5	5	340
846506657	36	180	45	2	5	5	250
846614790	28	180	45	2	5	5	500
846700359	51	180	45	2	5	5	600

			Job Summary Report					
JobID	ProductID	Prod.Qty	ReqdDate	Start	Starttime	Mach #	ProcTime	ToolID
925	846028520	1000	11/2/93	11/1/93	0	10	9	84SP0304A
927	846028530	2000	11/2/93	11/1/93	0	9	16	84SP0305A
929	846457992	700	11/2/93	11/1/93	16	9	12	108JK8508
931	846458008	100	11/2/93	11/1/93	9	10	4	84SP0304A
933	846477792	1100	11/2/93	11/1/93	0	7	10	84PSO312A
935	846506657	775	11/2/93	11/1/93	13	10	8	98RE2143A
937	846614790	670	11/2/93	11/1/93	0	6	7	89SP0052B
939	846700359	1500	11/2/93	11/1/93	0	8	12	85SO0101A
941	846028520	1500	11/9/93	11/8/93	0	10	12	84SP0304A
943	846028530	400	11/9/93	11/8/93	0	9	6	84SP0305A
945	846457992	890	11/9/93	11/8/93	6	9	14	108JK8508
947	846458008	1050	11/9/93	11/8/93	12	10	10	84SP0304A
949	846477792	2000	11/9/93	11/8/93	0	8	16	84PSO312A
951	846506657	475	11/9/93	11/8/93	22	10	6	98RE2143A
953	846614790	540	11/9/93	11/8/93	0	6	6	89SP0052B
955	846700359	960	11/9/93	11/8/93	0	7	9	85SO0101A
957	846028520	500	11/16/93	11/15/93	0	10	6	84SP0304A
959	846028530	760	11/16/93	11/15/93	0	9	8	84SP0305A
961	846457992	1250	11/16/93	11/15/93	8	9	19	108JK8508
963	846458008	1000	11/16/93	11/15/93	6	10	9	84SP0304A
965	846477792	1000	11/16/93	11/15/93	0	8	9	84PSO312A
967	846506657	775	11/16/93	11/15/93	15	10	8	98RE2143A
969	846614790	370	11/16/93	11/15/93	0	6	5	89SP0052B
971	846700359	875	11/16/93	11/15/93	0	7	8	85SO0101A
973	846028520	1400	11/23/93	11/22/93	0	10	12	84SP0304A
975	846028530	775	11/23/93	11/22/93	0	9	8	84SP0305A
977	846457992	560	11/23/93	11/22/93	8	9	10	108JK8508
979	846458008	100	11/23/93	11/22/93	12	10	4	84SP0304A
981	846477792	670	11/23/93	11/22/93	0	6	7	84PSO312A
983	846506657	540	11/23/93	11/22/93	16	10	6	98RE2143A
985	846614790	850	11/23/93	11/22/93	0	7	8	89SP0052B
987	846700359	2000	11/23/93	11/22/93	0	8	16	85SO0101A
989	846028520	156	11/30/93	11/29/93	0	10	4	84SP0304A
991	846028530	600	11/30/93	11/29/93	0	9	7	84SP0305A
993	846457992	1700	11/30/93	11/29/93	7	9	24	108JK8508
995	846458008	775	11/30/93	11/29/93	4	10	8	84SP0304A
997	846477792	990	11/30/93	11/29/93	0	7	9	84PSO312A
999	846506657	1150	11/30/93	11/29/93	12	10	10	98RE2143A
1001	846614790	900	11/30/93	11/29/93	0	6	9	89SP0052B
1003	846700359	1500	11/30/93	11/29/93	0	8	12	85SO0101A
1005	846028520	1700	12/7/93	12/6/93	0	10	14	84SP0304A
1007	846028530	670	12/7/93	12/6/93	0	9	7	84SP0305A
1009	846457992	775	12/7/93	12/6/93	7	9	13	108JK8508
1011	846458008	990	12/7/93	12/6/93	14	10	9	84SP0304A
1013	846477792	1100	12/7/93	12/6/93	0	8	10	84PSO312A
1015	846506657	775	12/7/93	12/6/93	23	10	8	98RE2143A
1017	846614790	790	12/7/93	12/6/93	0	6	8	89SP0052B
1019	846700359	900	12/7/93	12/6/93	0	7	9	85SO0101A
1021	846028520	1500	12/14/93	12/13/93	0	10	12	84SP0304A
1023	846028530	400	12/14/93	12/13/93	0	9	6	84SP0305A
1025	846457992	890	12/14/93	12/13/93	6	9	14	108JK8508
1027	846458008	1050	12/14/93	12/13/93	12	10	10	84SP0304A

JobID	ProductID	Prod.Qty	ReqdDate	Start	Starttime	Mach #	ProcTime	ToolID
1029	846477792	2000	12/14/93	12/13/93	0	8	16	84PSO312A
1031	846506657	475	12/14/93	12/13/93	22	10	6	98RE2143A
1033	846614790	540	12/14/93	12/13/93	0	6	6	89SP0052B
1035	846700359	960	12/14/93	12/13/93	0	7	9	85SO0101A
1037	846028520	1750	12/21/93	12/20/93	0	10	14	84SP0304A
1039	846028530	650	12/21/93	12/20/93	0	9	7	84SP0305A
1041	846457992	500	12/21/93	12/20/93	7	9	9	108JK8508
1043	846458008	590	12/21/93	12/20/93	14	10	7	84SP0304A
1045	846477792	1000	12/21/93	12/20/93	0	8	9	84PSO312A
1047	846506657	400	12/21/93	12/20/93	21	10	6	98RE2143A
1049	846614790	780	12/21/93	12/20/93	0	7	8	89SP0052B
1051	846700359	670	12/21/93	12/20/93	0	6	7	85SO0101A
1053	846028520	990	12/28/93	12/27/93	0	10	9	84SP0304A
1055	846028530	1500	12/28/93	12/27/93	0	9	12	84SP0305A
1057	846457992	600	12/28/93	12/27/93	12	9	10	108JK8508
1059	846458008	575	12/28/93	12/27/93	9	10	7	84SP0304A
1061	846477792	900	12/28/93	12/27/93	0	7	9	84PSO312A
1063	846506657	530	12/28/93	12/27/93	16	10	6	98RE2143A
1065	846614790	975	12/28/93	12/27/93	0	6	9	89SP0052B
1067	846700359	1100	12/28/93	12/27/93	0	8	10	85SO0101A
1069	846028520	890	1/4/94	1/3/94	0	10	9	84SP0304A
1071	846028530	980	1/4/94	1/3/94	0	9	9	84SP0305A
1073	846457992	800	1/4/94	1/3/94	9	9	13	108JK8508
1075	846458008	400	1/4/94	1/3/94	9	10	6	84SP0304A
1077	846477792	875	1/4/94	1/3/94	0	8	8	84PSO312A
1079	846506657	530	1/4/94	1/3/94	15	10	6	98RE2143A
1081	846614790	780	1/4/94	1/3/94	0	7	8	89SP0052B
1083	846700359	750	1/4/94	1/3/94	0	6	8	85SO0101A
1085	846028520	1500	1/11/94	1/10/94	0	10	12	84SP0304A
1087	846028530	400	1/11/94	1/10/94	0	9	6	84SP0305A
1089	846457992	890	1/11/94	1/10/94	6	9	14	108JK8508
1091	846458008	1050	1/11/94	1/10/94	12	10	10	84SP0304A
1093	846477792	2000	1/11/94	1/10/94	0	8	16	84PSO312A
1095	846506657	475	1/11/94	1/10/94	22	10	6	98RE2143A
1097	846614790	440	1/11/94	1/10/94	0	6	6	89SP0052B
1099	846700359	960	1/11/94	1/10/94	0	7	9	85SO0101A
1101	846028520	1500	1/18/94	1/17/94	0	10	12	84SP0304A
1103	846028530	400	1/18/94	1/17/94	0	9	6	84SP0305A
1105	846457992	890	1/18/94	1/17/94	6	9	14	108JK8508
1107	846458008	1050	1/18/94	1/17/94	12	10	10	84SP0304A
1109	846477792	2000	1/18/94	1/17/94	0	8	16	84PSO312A
1111	846506657	475	1/18/94	1/17/94	22	10	6	98RE2143A
1113	846614790	740	1/18/94	1/17/94	0	6	8	89SP0052B
1115	846700359	960	1/18/94	1/17/94	0	7	9	85SO0101A
1117	846028520	750	1/25/94	1/24/94	0	10	8	84SP0304A
1119	846028530	1000	1/25/94	1/24/94	0	9	9	84SP0305A
1121	846457992	1100	1/25/94	1/24/94	9	9	17	108JK8508
1123	846458008	900	1/25/94	1/24/94	8	10	9	84SP0304A
1125	846477792	700	1/25/94	1/24/94	0	8	7	84PSO312A
1127	846506657	300	1/25/94	1/24/94	17	10	5	98RE2143A
1129	846614790	550	1/25/94	1/24/94	0	7	6	89SP0052B
1131	846700359	400	1/25/94	1/24/94	0	6	6	85SO0101A
1133	846028520	2000	2/1/94	1/31/94	0	10	16	84SP0304A
1135	846028530	775	2/1/94	1/31/94	0	9	8	84SP0305A

JobID	ProductID	Prod.Qty	ReqdDate	Start	Starttime	Mach #	ProcTime	ToolID
1137	846457992	650	2/1/94	1/31/94	8	9	11	108JK8508
1139	846458008	900	2/1/94	1/31/94	16	10	9	84SP0304A
1141	846477792	1100	2/1/94	1/31/94	0	8	10	84PSO312A
1143	846506657	1775	2/1/94	1/31/94	25	10	14	98RE2143A
1145	846614790	900	2/1/94	1/31/94	0	7	9	89SP0052B
1147	846700359	850	2/1/94	1/31/94	0	6	8	85SO0101A

APPENDIX 3

MACHINE OUTPUT SCHEDULE

The system generates the machine output schedule based on the Longest Processing Time algorithm. The format contains the date of the week, machine #, Utilization time of the machines, the number of jobs linked to the machines followed by the jobs.

Week	Machine	util	us	ue	se	sl	seq1	seq2	seq3
11/1/93	6	7	0	7	1	1	937		
	7	10	0	10	1	1	933		
	8	12	0	12	1	1	939		
	9	28	0	28	2	2	927	929	
	10	21	0	21	3	3	925	931	935
11/8/93	6	6	0	6	1	1	953		
	7	9	0	9	1	1	955		
	8	16	0	16	1	1	949		
	9	20	0	20	2	2	943	945	
	10	28	0	28	3	3	941	947	951
11/15/93	6	5	0	5	1	1	969		
	7	8	0	8	1	1	971		
	8	9	0	9	1	1	965		
	9	27	0	27	2	2	959	961	
	10	23	0	23	3	3	957	963	967
11/22/93	6	7	0	7	1	1	981		
	7	8	0	8	1	1	985		
	8	16	0	16	1	1	987		
	9	18	0	18	2	2	975	977	
	10	22	0	22	3	3	973	979	983
11/29/93	6	9	0	9	1	1	1001		
	7	9	0	9	1	1	997		
	8	12	0	12	1	1	1003		
	9	31	0	31	2	2	991	993	
	10	22	0	22	3	3	989	995	999
12/6/93	6	8	0	8	1	1	1017		
	7	9	0	9	1	1	1019		
	8	10	0	10	1	1	1013		
	9	20	0	20	2	2	1007	1009	
	10	31	0	31	3	3	1005	1011	1015
12/13/93	6	6	0	6	1	1	1033		
	7	9	0	9	1	1	1035		
	8	16	0	16	1	1	1029		
	9	20	0	20	2	2	1023	1025	
	10	28	0	28	3	3	1021	1027	1031
12/20/93	6	7	0	7	1	1	1051		
	7	8	0	8	1	1	1049		
	8	9	0	9	1	1	1045		
	9	16	0	16	2	2	1039	1041	
	10	27	0	27	3	3	1037	1043	1047
12/27/93	6	9	0	9	1	1	1065		
	7	9	0	9	1	1	1061		
	8	10	0	10	1	1	1067		
	9	22	0	22	2	2	1055	1057	
	10	22	0	22	3	3	1053	1059	1063
1/3/93	6	8	0	8	1	1	1083		
	7	8	0	8	1	1	1081		
	8	8	0	8	1	1	1077		

Week	Machine	util	us	ue	se	sl	seq1	seq2	seq3
	9	22	0	22	2	2	1071	1073	
	10	21	0	21	3	3	1069	1075	1079
1/10/93	6	6	0	6	1	1	1097		
	7	9	0	9	1	1	1099		
	8	16	0	16	1	1	1093		
	9	20	0	20	2	2	1087	1089	
	10	28	0	28	3	3	1085	1091	1095
1/17/93	6	8	0	8	1	1	1113		
	7	9	0	9	1	1	1115		
	8	16	0	16	1	1	1109		
	9	20	0	20	2	2	1103	1105	
	10	28	0	28	3	3	1101	1107	1111
1/24/93	6	6	0	6	1	1	1131		
	7	6	0	6	1	1	1129		
	8	7	0	7	1	1	1125		
	9	26	0	26	2	2	1119	1121	
	10	22	0	22	3	3	1117	1123	1127
1/31/93	6	8	0	8	1	1	1147		
	7	9	0	9	1	1	1145		
	8	10	0	10	1	1	1141		
	9	19	0	19	2	2	1135	1137	
	10	39	0	39	3	3	1133	1139	1143

APPENDIX 4

MRP TABLEAU

The system generates the MRP tableau based on the Net Change MRP algorithm. The MRP Tableau shows the Product ID, New requirements and the production quantity. The following process parameters is constant.

Starting Inventory for all the products is 0

Product ID	**Batch Size**	**Break Even Job Size**
846028520	75	50
846028530	100	50
846457792	60	30
846458008	50	55
846477792	100	20
846506657	50	20
846614790	300	150
846700359	50	75

							MRP Tableau					
ID	ProductID	Inv	N.Reqt0	N.Reqt1	N.Reqt2	N.Reqt3	N.Reqt4	ProdQty0	ProdQty1	ProdQty2	ProdQty3	ProdQty4
570	846028520	0	1000	950	1050	500	200	1000	950	1050	500	200
571	846028530	0	2000	1250	550	300	600	2000	1250	550	300	600
572	846457992	0	700	750	400	290	100	700	750	400	290	100
573	846458008	0	100	250	300	300	200	100	250	300	300	200
574	846477792	0	1100	670	800	550	430	1100	670	800	550	430
575	846506657	0	775	950	530	200	400	775	950	530	200	400
576	846614790	0	670	1000	550	475	850	670	1000	550	475	850
577	846700359	0	1500	975	1000	750	865	1500	975	1000	750	865
578	846028520	0	1500	810	675	600	900	1500	810	675	600	900
579	846028530	0	400	1750	550	775	100	400	1750	550	775	100
580	846457992	0	890	550	875	675	500	890	550	875	675	500
581	846458008	0	1050	650	650	890	400	1050	650	650	890	400
582	846477792	0	2000	870	300	450	970	2000	870	300	450	970
583	846506657	0	475	950	900	300	550	475	950	900	300	550
584	846614790	0	540	600	850	100	200	540	600	950	850	300
585	846700359	0	960	975	700	960	150	960	975	700	960	150
586	846028520	0	500	450	800	200	100	500	450	800	200	100
587	846028530	0	760	850	750	530	300	760	850	750	530	300
588	846457992	0	1250	650	900	700	600	1250	650	900	700	600
589	846458008	0	1000	375	550	775	520	1000	375	550	775	520
590	846477792	0	1000	950	530	200	200	1000	950	530	200	200
591	846506657	0	775	950	530	200	400	775	950	530	200	400
592	846614790	0	370	800	760	500	675	370	900	660	500	675
593	846700359	0	875	400	100	665	725	875	400	100	665	725
594	846028520	0	1400	1000	940	600	850	1400	1000	940	600	850
595	846028530	0	775	950	530	200	400	775	950	530	200	400
596	846457992	0	560	800	978	350	200	560	800	978	350	200
597	846458008	0	100	250	300	300	200	100	250	300	300	200
598	846477792	0	670	1000	490	200	100	670	1000	490	200	100
599	846506657	0	540	870	400	450	250	540	870	400	450	250
600	846614790	100	750	400	290	100	50	850	300	390	725	0
601	846700359	0	2000	1005	800	740	300	2000	1005	800	740	300
602	846028520	0	156	570	100	400	100	156	570	100	400	100
603	846028530	0	600	450	550	675	200	600	450	550	675	200
604	846457992	0	1700	850	700	190	400	1700	850	700	190	400
605	846458008	0	775	900	500	600	100	775	900	500	600	100
606	846477792	0	990	790	865	650	230	990	790	865	650	230
607	846506657	0	1150	1250	550	475	850	1150	1250	550	475	850
608	846614790	-100	1000	750	865	300	300	900	850	865	300	300
609	846700359	0	1500	975	530	200	400	1500	975	530	200	400
610	846028520	0	1700	850	700	190	400	1700	850	700	190	400
611	846028530	0	670	1000	550	475	850	670	1000	550	475	850
612	846457992	0	775	900	500	600	100	775	900	500	600	100
613	846458008	0	990	790	865	650	230	990	790	865	650	230
614	846477792	0	1100	670	800	550	430	1100	670	800	550	430
615	846506657	0	775	950	530	200	400	775	950	530	200	400
616	846614790	100	690	780	660	500	400	790	780	560	500	400
617	846700359	0	900	875	650	200	275	900	875	650	200	275
618	846028520	0	1500	810	675	600	900	1500	810	675	600	900
619	846028530	0	400	1750	550	775	100	400	1750	550	775	100
620	846457992	0	890	550	875	675	500	890	550	875	675	500
621	846458008	0	1050	650	650	890	400	1050	650	650	890	400
622	846477792	0	2000	870	300	450	970	2000	870	300	450	970
623	846506657	0	475	950	900	300	550	475	950	900	300	550
624	846614790	0	540	600	850	100	200	540	500	1050	400	300
625	846700359	0	960	975	700	960	150	960	975	700	960	150
626	846028520	0	1750	875	900	800	550	1750	875	900	800	550
627	846028530	0	650	675	875	800	700	650	675	875	800	700
628	846457992	0	500	400	100	100	400	500	400	100	100	400
629	846458008	0	590	680	700	775	500	590	680	700	775	500
630	846477792	0	1000	900	800	600	400	1000	900	800	600	400
631	846506657	0	400	600	400	500	500	400	600	400	500	500
632	846614790	-100	880	970	900	775	700	780	1170	800	775	700
633	846700359	0	670	650	700	570	500	670	650	700	570	500
634	846028520	0	990	790	700	600	100	990	790	700	600	100
635	846028530	0	1500	750	350	575	550	1500	750	350	575	550
636	846457992	0	600	600	650	500	550	600	600	650	500	550
637	846458008	0	575	150	450	270	150	575	150	450	270	150
638	846477792	0	900	670	980	300	130	900	670	980	300	130
639	846506657	0	530	200	400	550	475	530	200	400	550	475
640	846614790	200	775	950	100	500	850	975	850	0	500	850
641	846700359	0	1100	670	290	750	865	1100	670	290	750	865
642	846028520	0	890	550	400	560	750	890	550	400	560	750
643	846028530	0	980	400	600	755	500	980	400	600	755	500

ID	ProductID	Inv	N.Reqt0	N.Reqt1	N.Reqt2	N.Reqt3	N.Reqt4	ProdQty0	ProdQty1	ProdQty2	ProdQty3	ProdQty4
644	846457992	0	800	880	650	750	550	800	880	650	750	550
645	846458008	0	400	150	450	270	150	400	150	450	270	150
646	846477792	0	875	920	400	250	190	875	920	400	250	190
647	846506657	0	530	670	290	750	865	530	670	290	750	865
648	846614790	-100	880	600	750	300	850	780	500	950	300	850
649	846700359	0	750	950	100	500	530	750	950	100	500	530
650	846028520	0	1500	810	675	600	900	1500	810	675	600	900
651	846028530	0	400	1750	550	775	100	400	1750	550	775	100
652	846457992	0	890	550	875	675	500	890	550	875	675	500
653	846458008	0	1050	650	650	890	400	1050	650	650	890	400
654	846477792	0	2000	870	300	450	970	2000	870	300	450	970
655	846506657	0	475	950	900	300	550	475	950	900	300	550
656	846614790	-100	540	600	850	100	200	440	800	850	850	300
657	846700359	0	960	975	700	960	150	960	975	700	960	150
658	846028520	0	1500	810	675	600	900	1500	810	675	600	900
659	846028530	0	400	1750	550	775	100	400	1750	550	775	100
660	846457992	0	890	550	875	675	500	890	550	875	675	500
661	846458008	0	1050	650	650	890	400	1050	650	650	890	400
662	846477792	0	2000	870	300	450	970	2000	870	300	450	970
663	846506657	0	475	950	900	300	550	475	950	900	300	550
664	846614790	200	540	600	850	100	200	740	600	750	300	300
665	846700359	0	960	975	700	960	150	960	975	700	960	150
666	846028520	0	750	775	950	400	650	750	775	950	400	650
667	846028530	0	1000	100	800	865	600	1000	100	800	865	600
668	846457992	0	1100	670	550	475	850	1100	670	550	475	850
669	846458008	0	900	550	900	800	100	900	550	900	800	100
670	846477792	0	700	1050	500	590	500	700	1050	500	590	500
671	846506657	0	300	670	1000	100	100	300	670	1000	100	100
672	846614790	0	550	475	850	300	200	550	375	950	300	300
673	846700359	0	400	475	100	650	85	400	475	100	650	85
674	846028520	0	2000	800	910	150	200	2000	800	910	150	200
675	846028530	0	775	675	250	600	400	775	675	250	600	400
676	846457992	0	650	400	370	200	150	650	400	370	200	150
677	846458008	0	900	540	540	490	206	900	540	540	490	206
678	846477792	0	1100	670	800	550	430	1100	670	800	550	430
679	846506657	0	1775	470	830	520	400	1775	470	830	520	400
680	846614790	-100	1000	700	975	550	475	900	800	975	550	475
681	846700359	0	850	550	100	650	300	850	550	100	650	300

REFERENCES

Anthony, R.H 1965, "*Planning and Control Systems: A Framework for Analysis*," Graduate School of Business, Harvard University, Cambridge.

Ashton, J.E.et.al. 1990, "Shop Floor Control in a System Job Shop: Definitely not MRP," P*roduction and Inventory Management Journal*, Second Quater, pp 27-31.

Baudin M. "Manufacturing Systems Analysis," Yourdon Press, New Jersey, pp 177 -345

Chase and Aquilano, "Production and Operations Management," Richard D. Irwin, Inc, Ontario

Gaither Norman, "Production and Operations Management," The Dryden Press, Hinsdale, Il, pp 504-553

Foo, George and Kinney L. "Materials Requirement Planning and Just-In Time Systems," Industrial Engineering Handbook, pp 10.85-11.01

Goodrich, T-(1989), "JIT and MRP can work together," *Automation*, April, pp 46-48.

Goldratt, Eliyahn and Jeff Cox, 1984 "The Goal," North River Press.

Graves, S.C. (1982) "Using Lagrangian Techniques to Solve HPP Problems," *Management Science*, Vol. 28, No.3-, pp 260-275.

Hax, A.C. and H.C. Meal (1975), "Hierarchical integration of production planning and Scheduling," in Studies in the Management Sciences, Vol.1, *Logisticss M.A Grisler (ed)* North Holland-American Elsevier, New York.

Hodgson, T.J. and D. Wang (1991a), "Optimal Hybrid push-pull control stategies for parallel multi-stage system : Part 1," *International Journal of production Research*, Vol.29 No.6, pp 1279-1287.

Hodgson, T.J. and D. Wang (1991b), "Optimal Hybrid push-pull control stategies for parallel multi-stage system : Part 11," *International Journal of production Research*, Vol.29 No.7, pp 1453-1460.

Johnson, S.M. 1954, "Optimal Two and Three Stage Production Schedules with Setup Times Included," *Naval Research Logistics Quarterly*, Vol.1, pp 61-68

Johnson, L.A. and D.C. Montgomery (1974), " *Operations Research in Production Planning, Scheduling and Inventory Control*," Wiley.

Krajewski, L.J. and Ritzman, L.P. (1987), "Operations Management," Addison-Welesly.

Krajewski, L.J., B.E. King, L.P. Ritzman and D.S. Wang (1987), "Kanban, MRP, and shaping the manufacturing environment," *Management Science*, Vol.33, No 1, pp 39-57

Monden, Y. 1983, "What Makes the Toyota production System Really Tick?" *Industrial Engineering*, Vol.13, No.5, pp 28-46.

Monden, Y. 1983, "Adaptable Kanban System Helps Toyota Maintain JIT Production " *Industrial Engineering*, Vol.13, No.5, pp 28-46.

Monden, Y. 1983, "Toyota Production Systems," IIE Press, Norcross, Georgia.

Meal, H.C., M.H.Wachter and D.C. Whybark (1987), "Materials Requirement Planning in Hierarchical Production Planning," *International Journal of Production Research*, Vol.25, No.7, pp 947-956.

Meleton, M .M. (1986), "OPT - Fantasy or Breakthrough?," *Production and Inventory Management*, Vol. 27, No.2, pp 13-21.

Mather Hall, "*Materials Requirement Planning and Inventory Control*,"

Nagendra, P., Phd Dissertation, "*Development of MRP 3*", Rutgers University, Newark, New Jersey.

Nahmias, S. (1989), "Production and Operation Analysis," Irwin.

Nathan, D. "*Simulation Based Scheduling*"

Pinedo, M. and G. Weiss (1979), "Scheduling Stocahstic Tasks on Two Parallel Processors;" *Naval Research Logistics Quarterly*, Vol. 26, pp 527-536.

Orlicky, J.A.(1976), "Materials Requirement Planning," McGraw-Hill, New York.

Ohno, T. (P982), "The Origin of Toyota Production System and Kanban System" in Applying Just-in-Time, IIE Press, Norcross, pp 3-8.

Roder I. Paul, "Finite Scheduling Systems," *APICS*, August 1993, pp 40-42

Sharma Ken, "Adding "Intelligence" To MRP Systems," *APICS*, March 1993, pp 53-58

Sugimoro, Y. (1977), "Toyota Production System and Kanban System," *International Journal of Production Research*, Vol. 15, No. 6, pp 553-564.

Spearman, M.L., D.L. Woodeff and W.J. Hopp (1990), "CONWIP: a pull alternative to Kanban," *International Journal of Production Research*, Vol.28, No.5, pp 879-894.

Spearman, M.L., D.L. Woodruff and W.J. Hopp (1989), "A hierarchical control architecture for constant WIP production systems," *Journal of Operations Management*, Vol.2, pp 142-171.

Turbide D. A. "MRP± The Adaption, Enhancement, and Application of MRP II," Industrial Press Inc,

Wight, O.W. 1984, "MRP II: Unlocking America's Productivity," Wight Publications, Williston, Vermont.

Williams, D. (1986), "JIT vs MRP: The push-pullers cal a truce," *Automotive Industries*, July, pp 30-31