The constraints and limitations of Manufacturing Resource Planning (MRP II) as a tool for shop floor control

by

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ABSTRACT

Manufacturing Resource Planning (MRP II) is a planning system used in various industries to manage manufacturing resources. This study explored the suitability of MRP II in controlling the shop floor by analyzing its constraints and limitations. The study is part of a larger effort by MIT's Production System Design Laboratory to establish an information system that meets the functional requirements of a physical (manufacturing) system. A literature survey of different books and papers on MRP II and Shop Floor Control was conducted and supplemented by interviews with individuals who have worked with MRP II systems. The production System Design Decomposition, a diagnostic tool developed by the Production System Design Laboratory was then used to determine what the constraints and limitations facing MRP II on the shop floor were. A case study at company X, a centrifuge manufacturer which uses MRP II in its production process was then used to tie in the issues raised from the literature survey with a real world example. The results of the literature review and the case study both revealed that MRP II was a poor tool for controlling the shop floor and proposed the use of hybrid systems that combined Kanban control with the strong planning capabilities of MRP II.

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Title: Professor of Mechanical Engineering

3. Acknowledgements and Biographical Note

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My entire family, for their support.

Martin Mbaya was born in Nairobi, Kenya on October 19, 1977. He attended primary school at Catholic Parochial School (January,1984 – March,1988) and Nyandarua Boarding Primary School (May,1988 – December,1991) where he received his Kenya Certificate of Primary Education (KCPE). Subsequently he joined Alliance High School (January,1992 – December,1995) where he received his Kenya Certificate of Secondary Education (KCSE). Soon after, he enrolled at Strathmore College (January 1996 – June 1996), a post high school institution based in Kenya, to study Information Systems and completed the first part of a diploma in IMIS (Institute for the Management of Information Systems). Before completing the diploma, he got enrolled at MIT (August 1996 – June 2000) where he will complete his Bachelors Degree in Mechanical Engineering and a concentration in Japanese in June 2000. While at MIT, he has traveled to China to carry out a seven-week Internet project at Fudan High School in Shanghai, China. He has also spent eleven weeks working on a machine design project at ULVAC limited (Japan's leading producer of equipment for the vacuum industry) in Chigasaki, Japan. While in Japan, he also got to visit the Toyota Assembly plant in Nagoya and witnessed first hand the Toyota Production System at work. In the USA, he has been involved in designing a Lean Manufacturing cell for Middleton Corporation, a manufacturer of parts for the aerospace industry. He has also studied the Lean Manufacturing system at United Electric (a manufacturer of flow meters for the processing industry) that has successfully implemented lean manufacturing principles in its plant located at Watertown, Massachusetts. Over a two-year period he has taken classes with Professor David Cochran, Director of the Production Design System Laboratory. The PSD Laboratory is part of the Laboratory for Manufacturing and Productivity in MIT's Mechanical Engineering department. Martin is also a cofounder of the MIT-AITI program, an initiative that is sending MIT students to African Schools to carry out 5-week long Internet related projects that help to bridge the digital divide between Africa and the West.

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Chapter 1 - Introduction

The Shop Floor is an integral part of any manufacturing system. It is here that the needs of the customer and the efforts of a manufacturing firm are inter-linked by combining raw materials and labor to make the desired finished product. Consequently, it is important that there should exist an effective means for controlling the activities of the shop floor in order to achieve the greatest efficiency and predictability of the manufacturing process.

Different manufacturing systems exist worldwide. In the USA Manufacturing Resource Planning (MRP II) is in use by close to 80% of the manufacturing industry [*rough estimate by Scott Ball - LFM*]. Initially introduced in the 1960s, MRP II has undergone several revisions fuelled by increased computing capabilities and an effort to integrate the activities of the different sections of the manufacturing firm into one unit. The latest version of MRP is the Advanced Planning System (APS).

This study tries to establish the suitability of MRP II as a tool for Shop Floor control. In general, MRP II is an excellent planning tool especially with regards to optimizing the use of the various manufacturing resources. However at the shop floor level, it experiences certain limitations that constrain its ability to act as an effective tool for control. The study also attempts to identify what these limitations are and to highlight different solutions that have been proposed or implemented by various companies and researchers to bring MRP II as close as possible to the ideal control system.

The scope of the paper is limited only to discussing how MRP II relates to shop floor control in the context of manufacturing. Some technical details of relevance are defined in the paper. In addition, definitions and explanations of the different MRP II concepts that are discussed are given. The paper is divided into two parts. The first part constituting chapters 2, 3 and 4 provides a review of the literature available on the topics of MRP II and Shop Floor Control. Chapter 2 begins by giving a description of MRP II. In addition to explaining what it is and how it works, it mentions how the shop floor control module is related to the entire MRP II framework. It also points out problems that are typically associated with MRP II and then proceed to highlight the types of solutions that industry has implemented in the form of MRP II hybrid systems. Chapter 3 discusses what shop floor control (SFC) is and what it entails. It then discusses what the characteristics of the ideal shop floor control design would be. It augments this with a discussion on the difference between push and pull systems with respect to shop floor control. Chapter 4 relates the contents of the previous two chapters by discussing how MRP II establishes shop floor control. It highlights the difficulties faced in doing this by identifying the limitations and constraints of the system using the Manufacturing System Design Decomposition developed by Professor Cochran. It then discusses from a technical viewpoint the various MRP hybrid systems that have arisen to solve these shortcomings as introduced in chapter 2. The second part of the paper is chapter 5 which provides a case study of a manufacturing firm that uses MRP II in its production process. Through the case study, the paper tries to connect the various characteristics highlighted in the literature review with a real life example. Chapter six gives the conclusions of the study.

Chapter 2 - Manufacturing Resource Planning (MRP II)

2.1 What is MRP II and why is it being used?

2.1.1 Definition and History

Manufacturing Resource Planning (MRP II) is defined by the American Production and Inventory Control Society (APICS) as a method for the effective planning of all the resources of a manufacturing company (Higgins, Leroy and Tierney 1996). It is a direct descendant of the Material Requirements Planning (MRP) system, which is a set of techniques that uses bills of material, inventory, data and a master production schedule to calculate the requirements for materials in a manufacturing company.

The MRP system was initiated in the 1960s and was spearheaded by a team of IBM innovators comprising Joe Orlicky, George Plossl, and Ollie Wright who sought to create a structured methodology for planning and scheduling materials for complex manufactured products. Over the past 30 years MRP has spawned an entire industry in manufacturing and professional services. It has evolved hand in hand with technological advancements in the computer hardware industry. Initially, MRP systems were run on large mainframe computers costing thousands of dollars and required large technical staffs to support them. However in the 1970s they underwent refinements that saw disparate modules get included and critical business concerns such as cost accounting and Capacity Requirements Planning get added. This gave rise to a new generation system called MRP II. Continued changes spurred by increased technological advances coupled with the expansion of the global business marketplace has led to changes in MRP II to enable it to facilitate the operations of the entire business enterprise. These changes have given rise to Enterprise Resource Planning (ERP) systems. ERP systems integrate quality, human resources, Information Technology (IT) and payroll systems into the MRP framework.

This paper concentrates on MRP II in the context of the manufacturing shop floor.

The characteristics of MRP II can be summarized as follows:

- The operation and financial system are the same
- It has simulation capabilities that enable predictions to be made beforehand.
- It involves every facet of business from planning to execution

(Higgins, Leroy and Tierney, 1996)

MRP II offers a systematic method for planning and procuring materials to support production. It constitutes relatively simple ideas implemented using a computer.

2.1.2 MRP II hierarchy

MRP II provides a general control structure that breaks the production control problem into a hierarchy based on time scale and product aggregation. One version of an MRP II hierarchy is shown in figure1 (Toomey 1996). Such a structure makes it possible for a manufacturer to address the daunting task of coordinating thousands of orders with hundreds of tools for thousands of end items made up of additional thousands of components.

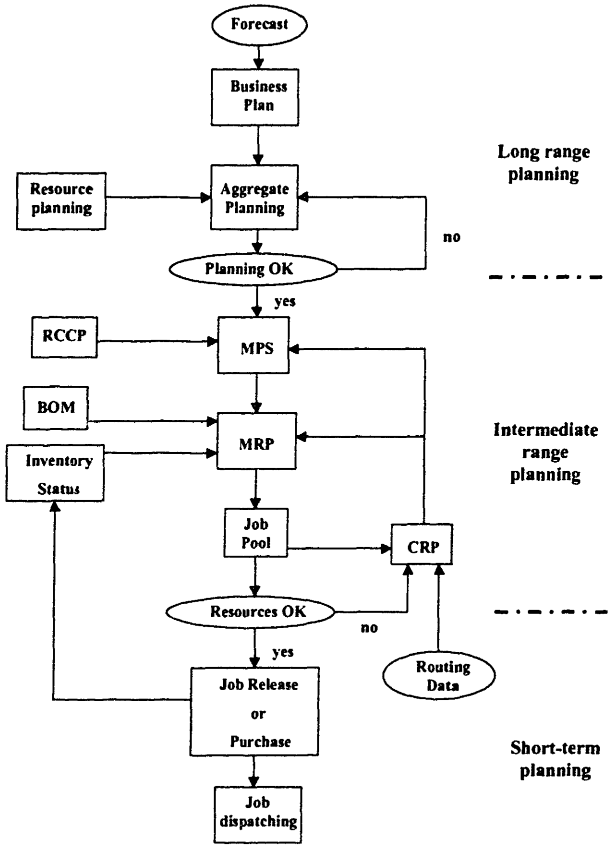

Figure 1: MRP II hierarchy

There are many different forms of the MRP II hierarchy but generally all of them constitute three major parts: long range planning, intermediate-range planning and short-term control as shown on the right hand side of figure 1. Activities carried out during Shop Floor Control fall under the intermediate planning and short-term control categories. Descriptions of the various items that constitute the three parts of the MRP II hierarchy are given by Spearman, Toomey and Higgins in their various books. An amalgam of these is presented below.

Long Range Planning

The scope for this level of planning ranges from six months to five years while re-planning may vary from a monthly to an annual basis. The level of detail is based on the part family. This level of planning is usually conducted at the corporate level and the decisions made typically impact all the plants belonging to one manufacturing firm. Long range planning constitutes three activities: forecasting, resource planning and aggregate planning. *Forecasting* predicts demands in the future. It is important for determining capacity, tooling and personnel. *Resource planning* determines the capacity requirements over the long term. This would help to determine whether to build a new plant or expand an existing one. *Aggregate planning* determines the level of production, staffing, inventory, overtime over the long term based on months and part families. This information enables management to make decisions such as whether to build up inventory or use overtime, or a combination of the two to meet increased demand for a product.

Intermediate Planning

Intermediate planning involves planning the different functions that take place during production. Intermediate Planning constitutes Demand Management, Master Production Schedule (MPS), Rough-Cut Capacity Planning, Bill of Resources, Material Requirements Planning and Capacity Requirements Planning. *Demand Management* is the process of converting the long-term aggregate forecast into a detailed forecast while tracking individual customer orders. The *Master Production Schedule (MPS)* is the source of demand for the MRP II system. The MPS gives the quantity and due dates for all parts that have independent demand. Independent demand refers to the demand for all end items and external demand for spare parts. *Rough-Cut Capacity Planning (RCCP)* provides a quick capacity check of a few critical resources to ensure the feasibility of the MPS. It uses a Bill of Resources (also referred to as a Bill of Materials when only dealing with materials) for each end item on the MPS. The *Bill of Resources* gives a breakdown of the time in hours needed at each critical resource required to build a particular end item. One form of this is the *Bill of Materials* (BOM). The BOM provides the relationship between end items (finished products) and lower level items (the constituent parts of the end item). *Material Requirements Planning* conducts allocation and carries out the job release function. It does this by releasing materials onto the shop floor and converting them into scheduled receipts. Its output is the job pool, which consists of planned order releases. MRP plays a key role in controlling the shop floor as will be discussed in chapter 4.

Capacity Requirements Planning (CRP) provides a more detailed capacity check on the production plans compared to RCCP. Its inputs are: planned order releases, existing WIP positions, routing data and capacity and lead times for all the work centers. CRP carries out infinite forward loading by predicting the job completion time for each process center using given fixed lead times and then predicting a given loading over time. These loading values are then compared against available capacity without making corrections for overloading. This aspect is one of the key weaknesses of MRP II in shop floor control and will be discussed later in this chapter.

Short Term control

Short Term control comes into play whenever a job is released to the shop floor or when a purchase order is released to vendors, so as to ensure on time completion with the correct quantity and specifications. A purchase order is used with purchased components while *Shop Floor Control* (SFC) is used with jobs destined for internal manufacture. Short Term control serves two functions: job dispatching and input / output control.

Job dispatching provides rules for arranging the queue in front of each work station on the plant floor such that due date integrity is maintained while machine utilization is kept high and manufacturing times are kept low. There are different job dispatching rules that exist and at least 100 can be found in common use. These include: Shortest Process Time (SPT), Least Slack, Least Slack per remaining operation, Critical Ratio. (Blackstone et al. 1982).

Input / Output control provides an easy way to check releases against available capacity. On the shop floor, it does this by monitoring the level of *Work in Progress (WIP)* at each work center. Depending on the level of WIP as compared to a predetermined level, the release rate is maintained or adjusted by changing the MPS until the correct rate is achieved for a given set of conditions.

2.2 What are the problems of MRP II?

The fundamental problem with the MRP II system is that it is based on a flawed model. This model relates dependent and independent demand and can be stated as follows:

'Dependent demand and independent demand are different. Production to meet dependent demand should be scheduled so as to explicitly recognize its linkage to production so as to meet independent demand'.

Dependent demand refers to the demand for components that are used to make independent demand products. Independent demand refers to the demand that originates from outside the system (Spearman).

This model causes MRP to assume a *fixed lead time* and *infinite capacity* which are common problems that afflict the system. Another consequence is *system nervousness*. *Lead time* refers to the span of time required to perform a process or a series of operations starting from when the need is initially recognized to the moment of completion. In MRP, the responsibility for lead time reduction is removed from the shop floor and consequently the people don't need to work faster than it. A fixed lead time also assumes that the production environment is constant. This is almost never the case since an entire host of problems constantly arise on the shop floor ranging from machine breakdown to the delay in arrival of various components. *Capacity* refers to the amount of labor and machine resources needed to accomplish the open shop orders and planned orders on the shop floor. Since the lead time is independent of the process centers, MRP II assumes infinite capacity on the plant floor. Spearman and Hopp point out how this situation is caused by the CRP module discussed earlier in the chapter. Typically, the CRP module will predict the job completion time for each work station using the predetermined fixed lead times. It will then use this to determine a predicted loading over time which will be compared to the available capacity on the shop floor. However they system is not designed to a make a correction for an overloaded situation. The system will usually point out that a problem has occurred but it will not point out what the problem is or suggest a solution to it. Consequently when overload conditions arise no remedy is offered (Hopp and Spearman 1996, 139). *System nervousness* refers to the large changes encountered in the Planned order releases when small changes are done to the Master Production Schedule.

Karmakar argues MRP II promises manufacturing managers more precision than it can deliver, requires unnecessary information and demands more formal discipline than the shop floor needs (Karmakar 1989, 1). Precision refers to the ability of a manufacturing process or system to deliver consistent performance all the time. These are symptoms of the rigidity caused by the fixed lead time and the infinite capacity assumption. Since MRP II is based on a scheduling system implemented by a computer, it often does not function seamlessly with the dynamic nature of a production system. One would therefore expect to see a proliferation of ad hoc solutions on the shop floor of a company running MRP II. This would occur in instances where the MRP II logic fails to meet the reality of the shop floor. This will be illustrated in the case study in chapter 5.

Other problems of MRP II include the high cost of software and hardware coupled with expenses incurred for training and implementation. An illustration of this is Visteon, the world's second largest automotive supplier with annual revenues of about $17 billion. Secondly, MRP II has an unnecessarily complex and centralized nature that requires the planning and co-ordination of material flow and the production of order releases to the shop floor. This property results in the central computer being tied up for hours on end depending on how often and how detailed the exploded bill of materials has to be. MRP II generally has very large data requirements with output that is both voluminous and tedious. Consequently some of the information collected usually turns out to be inaccurate.

2.3 What solutions are being proposed to solve these problems?

On a short-term basis the greatest effort has been put into creating more efficient Data Processing techniques and better user interfaces (Karmakar, 1989). However on a longer term, no notable efforts seem to have been suggested to address the problems that plague MRP. Such solutions would call for a complete overhaul of the model described earlier in the chapter. Instead of doing this, a lot of effort has gone into revising and expanding the functionality of MRP II resulting in systems like ERP and APS described in chapter 1. In addition, new advances in the computer industry, primarily processing speeds and storage capacity, have led to a greater emphasis on optimizing the computer related aspects of MRP while completely ignoring the underlying problems with the MRP logic.

For the problem of responsiveness, Rusk in his paper entitled "The Role of Bill of Materials in Manufacturing Systems" proposes the Bill Of Materials as a solution. He points out that better use of the BOM would enable suppliers to estimate part usage of the manufacturers and also increase flexibility. For system nervousness, Benton proposes the elimination of day to day operation failures as a solution. However, he points out that MRP's rigidity cannot be overcome unless the entire system is changed.

There have been several attempts to integrate MRP II with other systems like JIT and lean leading to various hybrid systems. Typically, such systems combine the strengths of pull and push systems leading to a design that best meets the needs of a given production system. Push and pull systems with regard to the shop floor are discussed in chapter 3. Karmakar proposes that an unlimited number of control methods can be developed in this way and goes on to identify three such systems that combine MRP and other techniques:

1. JIT-MRP – This is a modification of existing MRP II systems that adds pull elements while eliminating problems that are associated to the system's lack of responsiveness. It is appropriate for continuous-flow or level repetitive processes where production is at a level rate and lead times are constant. In this arrangement, MRP does not handle order releases but instead concentrates on materials co-ordination, materials planning and purchasing. The shop floor on the other hand is operated as a JIT flow system.

2. Tandem Push-Pull – These are characteristic of repetitive batch environments where lead times are fairly stable. These are usually assembly and subassembly environments where the manufacturing cycle time is significantly shorter than parts purchasing and fabrication lead times. Push and pull systems are juxtaposed such that MRP II ensures part availability based on end-item schedules and while kanban handles subassembly and assembly releases.

3. Requirement driven Kanban – In this setting, individual cells within a manufacturing chain are run using kanban control while MRP II runs the remaining processes. This is suitable for settings where final assembly schedules are unstable with respect to volume and mix but fairly stable demand can be predicted by certain portions of the production process. This hybrid system is particularly applicable in manufacturing shops that supply subassembly and assembly operations, where the mix may change significantly while the volume remains fairly constant. Builders of common subassemblies and metal forming operations also fall in this category.

Chapter 3 - Shop Floor Control

3.1 What is shop floor control (SFC)?

3.1.1 - Definition

Shop Floor Control is defined as a system for utilizing data from the shop floor to maintain and communicate status information on shop/manufacturing orders and work centers. (Higgins, Leroy and Tierney 1996). It forms the foundation of a production planning and control system and therefore plays a crucial role in the overall design of a manufacturing system. However since manufacturing systems are of such a large variety, different SFC designs exist and these are typically customizations that fit the specific needs of a given shop floor.

Scherer points out that the topic of Shop Floor Control is not well understood owing to a theory and practice gap between the situation in industry and in academia. In industry operator experience, motivation and qualifications form the basis of Shop Floor Control while academia concentrates on the problem of scheduling and its solution. In describing the situation in industry, he identifies the shop floor as a provider of physical goods He further states that it is faced with the challenge of becoming an agile entity within an enterprise and within a network of enterprises forming a virtual organization. He states that this challenge is posed by the current production environment, which is constantly faced by changes and dominating customer demand. An example of a study that tries to reconcile this gap is by Kenneth Mackay and John Buzacott whose paper entitled "The application of computerized production control systems in job shop environments" analyzes how the computer helps the scheduler to do the task of scheduling in a job shop environment. In his paper, he points out that analytical and alogorithmic aids have limited benefits to a typical job shop. He suggests that the appropriate use of computer technology can address information overload, cue filtering and assist the scheduler in problem solving.

3.1.2 Objectives of Shop Floor Control

Spearman and Hopp point out that Shop Floor Control plays an integral role in production and when properly implemented it satisfies 4 objectives:

i. It creates the ideal production system. In the various literature surveyed, the ideal case was described as a pull system (to be defined later in the chapter).

ii. It provides an enabling environment for the workers that makes the entire production system easy to understand. As a result the system becomes easy to use.

iii. It integrates easily with other planning functions. In the case of MRP II, this would mean an ability to execute the plans generated in long range planning and intermediate planning as well as providing feedback to refine these functions.

iv. It is has the flexibility to accommodate new ideas and changes. This objective is aimed at creating an agile system that can meet the challenges currently faced in industry. (Spearman and Hopp 1996,424)

3.1.3 Functions in Shop floor Control

Spearman and Hopp identify four general functions that are carried out in Shop Floor Control

- It ***co-ordinates the manufacturing resources*** (material, knowledge, humans and information) on the shop floor. Material flow control, which is a fundamental activity in most systems, falls under this category. This function provides a mechanism that decides which job to release to the factory, which job to work on at the individual workstations and what material to move between workstations.

- It provides ***real time control***. Real time simulations can be created based on the behavior of a plant which is determined by analyzing three sets of data:
  - Standard WIP which refers to the quantity and location of material between different manufacturing processes.
  - Status monitoring which involves the surveillance of manufacturing resources other than material such as staffing levels and machine status.
  - Throughput tracking which involves measuring the output from a line or plant against an established production quota or customer due date. This can then be used to forecast the need for overtime or staffing shifts.

- It carries out ***capacity feedback***, which involves the collection of data to update capacity estimates so as to ensure consistency between high level planning modules and low level execution ones.

- It enables ***quality control*** by giving the operator of a downstream workstation the authority to refuse parts from an upstream workstation on the basis of inadequate quality. (Spearman and Hopp 1996, 425)

3.2 What are the characteristics of a good SFC design?

Scherer describes shop floor control from a systems perspective. He notes that in order to achieve control within the shop floor, the designer's goal should be that of developing a dynamic and flexible organization as opposed to finding an optimal design. He gives a further breakdown of the SFC system using two different perspectives:

- Using cybernetic systems theory, the shop floor is part of a larger cybernetic system that is highly complex and has chaotic behavior. In such a system, the behavior is predictable only for a short time because of the interactions, feedback and coupling between the different aspects of the manufacturing system. The dynamics of behavior of the formal logic system and its state variables as encountered in the real world can subsequently be used to describe shop floor control.

- Using sociotechnical systems theory, emphasis is laid on the role of humans in production as they interact with machines on the shop floor. By using the patterns of social and human behavior, it is possible to describe and understand the action and logic of organizational development of informal systems. (Scherer 1998, 453).

With these two definitions in mind, Scherer proposes that the two important parameters to consider in designing a control system (hence the SFC module) are the ***structure of the system*** and the ***individual work tasks***.

In terms of structure, Spearman identifies three important considerations to bear in mind when designing the SFC.

1. Gross capacity control – Gross Capacity Control ensures that the lines on the plant floor are close to optimally loaded when running. This creates a stable environment for the production system. Gross capacity control can be achieved by varying shifts, staffing levels, days per week and hours per day or by using outside vendors.
2. Bottleneck planning – Bottle neck refers to the slowest process in a production system. Stable bottle neck provide the most ideal situation because they are easier to maintain than moving ones. It is worth noting however that bottlenecks can be designed by adding capacity to some stations so that throughput is never constrained.
3. Span of control – Span of control refers to the number of employees under the direct supervision of a manager as well as range of products and/or processes to be supervised. An ideal system will provide the manager with information about what is needed further downstream as well as information about the materials that will be arriving at different stations. This information enables him to plan effectively.

According to Scherer, a design that takes into account the individual work tasks should be able to instill a capacity for self-design and lasting adaptability in the shop floor control module. A system with this capacity gives the human an opportunity to achieve three things:

- Learn based on his qualifications and motivation
- Gain experience through errors
- Apply knowledge by carrying out independent actions.

In this way the human can contribute to the increased flexibility and adaptability of the entire production system without being driven to do so by people higher in the hierarchical framework. Ultimately, this enables the SFC module to meet objectives (i) and (iv) described above.

3.3 SFC in Push systems and Pull systems

In general, SFC systems are classified into two categories, Push and Pull, based on four different criteria. These are described below under separate headings. Benton and Shin provide the first three classifications while the fourth is proposed by Professor Cochran of the MIT Production System Design laboratory.

1. Nature of the order release (De Toni et al, 1988; Karmakar, 1989; Ding and Yuen 1991) -In ***pull*** systems, the order release by which the flow of materials or components is initiated gets triggered by the removal of an end item or a fixed lot of end items. In ***push*** systems, production or material flow is initiated in anticipation of future demand.

2. The structure of information flow (Olhager and Ostlund 1990; Hodgson & Wang (1991 a,b)) – In ***pull*** systems, local demand from the next server triggers the physical flow of materials. The local demand refers to orders while the server refers to a

workstation. Such a system is a decentralized control strategy where the ultimate goal of meeting orders is disregarded in local workstations. ***Push*** systems use global and centralized information in the form of customer orders and demand forecasts which are released and processed to control all the levels of the production cycle.

3. Practical approach associated with WIP level on the shop floor (Spearman and Zazanis 1992) – In ***pull*** systems, a closed queuing network is characterized by a bounded Work In Process (WIP). This places a cap on the maximum amount of WIP that can be found within a cell or between workstations on the shop floor. ***Push*** systems are characterized by an open queuing network with infinite queuing space.

4. Type of control system based on the classical control model (David S. Cochran 1994) – A ***pull*** system provides feedback each time a unit is produced. It uses a decoupler to detect the difference between the desired quantity and the actual quantity produced. The resulting error is converted into a signal that initiates production of the machines upstream of the decoupler. A ***push*** system is an open loop control system whereby the feedback in the output quantity is not used to effectively control the manufacturing system. Any disturbance occurring to the system causes a change in the output which is however not detected until the following planning cycle. This change is caused by the time delay in information.

Uday Karmakar summarizes the advantages of the two systems as follows:

Pull systems - are cheaper because they don't need computerization (software and hardware); leave control and responsibility at the local level; and offer attractive incentives for lead time management.

Push systems – are good at material planning and co-ordination; provide a hub for inter-functional communication and data management due to their centralized control; and are good at computing quantities for work releases by interpreting forecasts into discrete product orders but not so much for timing .The inability to meet the timing is caused by the lack of dependable feedback based on the output of the system.

By combining these complementary set of strengths, hybrid systems end up solving the weaknesses found in MRP II. Based on the above classifications and advantages, MRP II can be classified as a push system.

Chapter 4 - MRP II as a tool for shop floor control

4.1 How does MRP II attempt to achieve shop floor control?

MRP II is a push system with a type of feedback loop incorporated into its structure. Cochran consequently models MRP II as an open loop control system with a set of inputs and outputs connected by a transfer function (the MRP procedure) as shown in figure 2. Note that the inclusion of the feedback loop in the model makes it appear to be a closed loop system. The feedback loop represents the machine counts that are taken at certain predefined times. Cochran points out that the feedback is independent of the manufacturing system's operation since the sampling rate is too infrequent or too late. Hence, unlike a true closed loop system, MRP II doesn't perform according to the plan immediately after the plan has been released. This happens because the state of the system cannot be controlled due to the lack of feedback.

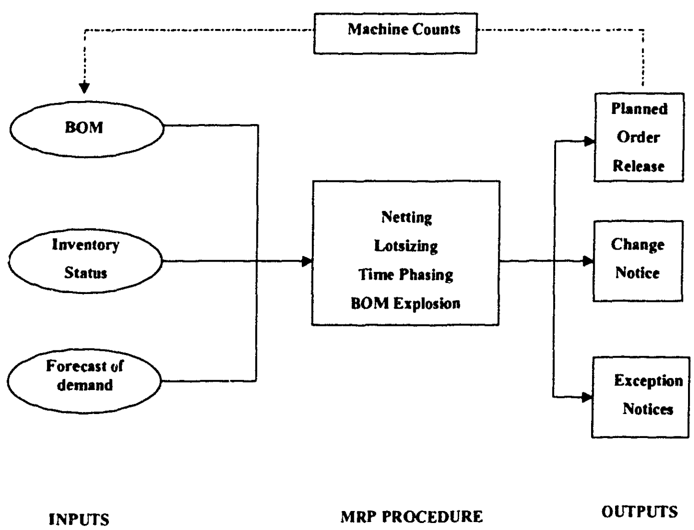

Figure 2. Modified open loop feedback control loop for MRP II shop floor control

Spearman and Hoff identify two dimensions that characterize shop floor control in MRP systems. First, MRP systems have to determine the appropriate **production quantities** for finished products requested through purchase orders and their component parts requested as jobs. Secondly, they need to establish **production timing** that will enable orders to be met by their due dates. This results into time being broken into intervals called **buckets** which range from a day to one week. The forecast demand is subsequently broken into discrete chunks based on these time buckets. Based on Cochran's open loop control system model, Spearman and Hoff identify three groups of elements in MRP: inputs, the MRP procedure and outputs. The interaction of these three elements is what facilitates the control of the shop floor in MRP II. The following discussion defines each of these three elements and discusses how they interact to bring about control. This model also incorporates the hierarchy introduced in chapter 2 and spans the categories of intermediate-range planning and short term control.

4.1.1 MRP Input

Three items constitute input into the MRP control system: the **forecast of demand for end items**, the associated **Bill of Materials (BOM)** and the **current inventory status**. This information is obtained from 3 sets of documents generated by the MRP system:

- Item Master File – In its basic form, this document contains a description of the part being manufactured, its BOM information, its lot sizing information and the planning lead time for the part. The item master file is organized by part number.

- Master Production Schedule – The MPS was discussed earlier in chapter 2. It contains the part number, the quantity needed and the due date for each purchase order. The MPS uses the part number to link the Item Master File with records where other processing information is located.
- Inventory Status File – This document provides information about the inventory status. This information helps to determine the quantity of demand that is met by on hand inventory and scheduled receipts. *On hand inventory* contains information describing a part, the location of the part and the number of parts that are at hand. It is stored by part number. *Scheduled receipts* contain the part number, the current quantity, the desired quantity and the due date. It stored by job number.

4.1.2 MRP Procedure

Using the input discussed above, MRP goes through five steps for each level of the bill of material (hence covering both dependent and independent demand) starting with end items. The procedure is iterative and is repeated until the entire BOM for a given part has been analyzed. The procedure is conducted as follows:

1. *Netting (Coverage Analysis)* – determines the net demand that cannot be met by scheduled receipts and on hand inventory. The two quantities are subtracted from the gross requirements identified by the MPS or by previous MRP operations.
2. *Lot sizing* - determines how jobs are sized so as to balance the conflicting need of minimizing inventory by using smaller lots and that of increasing capacity by using larger lots to avoid frequent setups. The lot size provides ideal production quantities

(jobs) to satisfy the net requirements. Different lot sizing rules exist and these include lot-for-lot, fixed Order Period and Period Order Quantity. (Toomey 1996)

3. *Time Phasing* – determines the lead time as an attribute of the part and the job. The job's start time can then be calculated by subtracting the lead time from the due date. Note that the status of the shop floor is not taken into account during this step of the procedure.
4. *BOM Explosion* – determine the gross requirements for the next level of the BOM using the start times and the lot sizes. This information is used to carry out netting during the next iterative step
5. *Iteration* – The entire procedure is repeated for a new level of the BOM.

4.1.3 MRP Output

Three items are produced as outputs of the MRP control system as discussed below:

- Planned Order Release – This document contains the part number, the number of units needed and the due date for the job. The planned order release eventually becomes the jobs that are processed on the shop floor.
- Change notices – These documents exist in two forms and are used to indicate modifications of existing jobs, their due dates and priorities. The first form is used in *expediting* orders (making their due date earlier) while the other is used in *deferring* orders (make their due date later).
- Exception reports – These documents are used to notify users of MRP that there are discrepancies between what is expected and what actually transpires. Such

differences would include job count differences, inventory discrepancies and defective parts.

4.2 What limitations and constraints are faced in using MRP II for shop floor control?

The limitations and constraints facing MRP II can be analyzed by contrasting its attributes to those of the ideal system identified in chapter 3. The Production System Design Laboratory at MIT uses a similar approach in studying different types of manufacturing systems. They have developed a diagnostic tool called the Manufacturing System Design Decomposition (appendix 1) which identifies the functional requirements (FR) and design parameters (DP) of a manufacturing system that is designed to maximize the long term return on investments. The decomposition provides a breakdown of the functional requirements and the corresponding design parameters for different levels of a manufacturing system. The paths of the deccmposition that relate to MRP II are highlighted in grey in the attached decomposition. The following discussion is broken down into seven subtopics and it highlights the limitations and constraints identified for MRP II using the decomposition. The first four are aimed at maximizing the sales revenue while the last three are aimed at decreasing the manufacturing costs.

<u>1. Quality</u>

An ideal control system will ensure that products are manufactured to within target design specifications. Before this can be achieved there must be an ability to assign causes of variation. However, owing to the delays associated with lot sizes and lead time, it takes a while before defects arising form such variations are identified in MRP. By this time, it is fairly hard to determine at which stage of the manufacturing process the defects were introduced and make the necessary corrections. This situation is true both for defects that arise as a result of the machine and those that may have been caused accidentally by the operator. In addition, the lack of control over upstream processes means that the downstream operator has to make do with defective parts until upper level management intervenes. Due to push nature, MRP systems do not lay a great emphasis on supplier quality programs and instead use a reactionary approach when they receive defective parts from their vendors.

Another weakness of the MRP II system is its failure to reduce the variation in the process output. As discussed in chapter 2, it is difficult to determine the source of problems in an MRP II system when the system gets loaded beyond its capacity. This occurs because of the systems inability to convert common causes into assignable causes. In addition, MRP II does not deal well with variation when this occurs. Professor Cochran points out that an MRP II system will usually oscillate out of control when a disturbance is introduced as opposed to pull systems which have self correcting capabilities (Cochran 1994, 226). This behavior is exhibited in the form system nervousness as identified in chapter 2 whereby small changes in the planned order releases is caused by small changes in the Master Production Schedule.

2. Identifying and resolving Problems

Here the goal is to ensure that products are delivered on time to the end customer. One way of achieving this requirement is by ensuring a quick response to production disruptions. MRP fails to respond quickly in three particular respects. There is a time lag between the occurrence of a disruption and its identification by the operator. This is a result of the infrequent counts done on the machines during production runs. Secondly, MRP II has a fairly complex material flow. Typically, parts move to different locations of the shop floor as they are transported from machine to machine and this makes it fairly hard to identify disruptions where they occur.

The third constraint is a consequence of the first two, namely, the feedback provided by MRP II is not context sensitive and is therefore not of much use.

3. Predictable output

A second way of ensuring that products are delivered on time is by minimizing the disruptions that occur to the system. This calls for an information system that is reliable and provides the relevant production information when needed. Unfortunately, the demand forecasts made by MRP II's long term planning module are rarely accurate. Often, production of rush orders may have to be made at short notice and causing disruption when orders have to be expedited or deferred.

In cases where workers are tied to machines in MRP II, disruptions are likely to occur anytime an allowance has to be made for the worker. This problem could easily be solved by having cross trained workers and a system design that enables workers from one station to co-ordinate two machines at one go. The severity of the disruption is a usually a function of how quickly a replacement worker can be trained or the amount of overtime hours that can be used to make up for lost time.

Other disruptions will occur if there are problems with the delivery of parts by material handlers. Since down stream workstations have no control over how parts are delivered, there may be timing problems from the time a part is finished until the time a new one starts being processed. Unlike a true pull system, no standard WIP is maintained between workstations. Usually this situation may call for large inventories to be maintained at the workstation to ensure that the machine never stays idle.

4. Delay Reduction

The ideal control system should also be able to ensure that the throughput time is less than or equal to the customer expected lead time. MRP II however, does not make an attempt to accomplish this objective. Instead it uses the lead time as a buffer against the various delays imposed on the system. These delays arise in four different ways and leads to the accumulation of inventory on the plant floor.

There is lot delay arising from the relatively large lot sizes typical in MRP II. All the parts in one lot must be processed at one workstation before they can move on to a new process and this occasionally leads to periods when downstream machines are not being used as they wait for all the parts in a previous process to be completed.

MRP faces process delay due to parts piling up behind bottleneck processes. The effect of this is that the speed of all downstream processes is limited to the pace set by the bottleneck process. MRP II tries to overcome this by using various job dispatching rules and ensuring that the bottleneck machine is always kept busy. By incorporating a pull mechanism, this problem can be overcome by defining a takt time (the time characterizing the customer demand and calculated by dividing the total customer demand by the total available machine time). All the machine times would consequently be designed to be less than or equal to takt time.

There is run size delay due to the large number of parts of the same type that have to be processed before changeovers can be done. The changeovers are necessary in order to meet the desired quantity and mix during a demand interval. These large run sizes are typically aimed at minimizing the number of setups and material changeovers that must be done at one demand interval as this tend to take a lot of time. This problem can be overcome by designing all the machines to have quick (less than one minute) setup and material changeover times.

Finally, transportation delay occurs in MRP II due to the departmental arrangement of different machines on the shop floor. As a result, parts have to travel great distances across the shop floor as they move from one process to another. To overcome this shortcoming, the shop floor should have a material flow oriented layout design.

5. Direct Labor

One way of minimizing manufacturing costs is by reducing the waste caused by unutilized labor. With MRP II this type of waste is observed in three different instances involving the operator. Since the operator is tied to a particular machine, he / she has to wait on the machine until it gets its job done. This time could be utilized more effectively especially if the machine was automated and designed to have minimal failure. The operator could then leave the machine running and attend to other tasks elsewhere. Other operators may also tie up operators further downstream especially if they are inefficient or careless in doing their work. In MRP this coupling is built into the system since the operators are not given the responsibility of managing the lead time. They also lack ownership over the parts or family of parts they make owing to the departmental nature of the shop floor. The third instance of wasted labor time is caused by the wasted motion of the operators. A shop floor controlled by MRP as well as the machines used with it are usually not designed with the operator's activities in mind. Consequently operators may have to walk long distances or repeat cumbersome routines as they work resulting in inefficiency. For example, in the case study presented in chapter 5, figure 7 (see appendix 2) shows the CNC lathe used at company X. In the foreground is a crate containing unprocessed parts. To load the parts onto the lathe, the worker has to walk back and forth and bend over to pick the heavy piece from the crate. An alternative design would have all the machines that process the part close to each other and between each machine would be a decoupler (conveniently designed so that the worker can load and unload it easily) The decoupler would hold parts that were not being processed. The lathe could also be designed for quick set up using SMED (Single Minute Exchange Dies) techniques. All these would simplify the worker's tasks significantly.

6. Indirect Labor

In Chapter 3, one of the considerations that was identified for an ideal shop floor design was the span of control. Managers who are usually not directly involved in the actual production work nevertheless need to ensure work on the shop floor is executed smoothly. MRP II fails in this respect because information is designed to flow top down. Feedback from the operators is rarely utilized in making improvements to the plant's performance. Consequently, a lot of the manager's time is spent handling crises that arise whenever the system goes out of control. MRP II also wastes indirect labor because of the large human resources it requires to schedule the system. Often, the elaborately arranged plans end up not being used when the production system fails to keep up with the plans made for it.

7. Facilities cost

The computing infrastructure necessary to keep MRP systems running makes them to be fairly expensive. In addition to this, the departmental layout of machines causes them to use up a lot of space on the shop floor. If the machines are designed with the manufacturing process in mind and are also arranged in cells based on part families or individual parts, much greater efficiency can be achieved in using the space.

4.3 How do MRP hybrid systems overcome these limitations and constraints?

Various solutions were proposed in Chapter 2 for solving the problems that plague MRP. One of this solutions was the use of hybrid systems (Karmakar 1989 8). In all the three hybrid systems that were proposed, MRP II assumed the role of making general guidelines that were subsequently used to achieve smooth running in the long run. A Kanban based system was then used to handle the details of daily production. Kanban is the operation control system of JIT production. Benton points out that Kanban control when used with a JIT based system is designed to minimize the work-in-process inventories by eliminating or reducing discrete batches. He also highlights conditions proposed by Monden and based on the Toyota Production System that are necessary for the Kanban controlled system to succeed. They include: smoothed production; job standardization; reduction of set-up time; improvement of activities; design of machine layout; automation of processes taking into account the human touch (Monden 1983). Benton also highlights 4 reasons why Kanban provides a superior control mechanism: it has less complexity, the feedback is faster and it has a reduced production lead time.

Production lead time refers to the duration of time allotted for the production of a part on a given line or routing (Spearmann and Hopp 1996, 224)

The MRP hybrid systems use an approach analogous to that of JIT by leaving MRP to handle the planning aspects of production while Kanban concentrates on control. Revisiting the three MRP hybrid versions introduced in Chapter 2, the complementary strengths of MRP II and Kanban can be identified as shown below:

JIT-MRP - The work is released by a pull mechanism thereby eliminating inventory. The system is designed to meet an overall daily or weekly demand instead of individual orders. To determine the inventory levels, a 'back-flush' is done. A backflush is an MRP technique that involves subtraction to allow for production that has taken place. Since they system does not keep track of individual orders, work is designed to flow along predictable paths and leave at predictable intervals. This arrangement is ideal for flow systems since it now incorporates flexibility that enables a different mix of products to be made with very quick turnarounds (Karmkar 1989, 9). JIT-MRP is shown in figure 3.

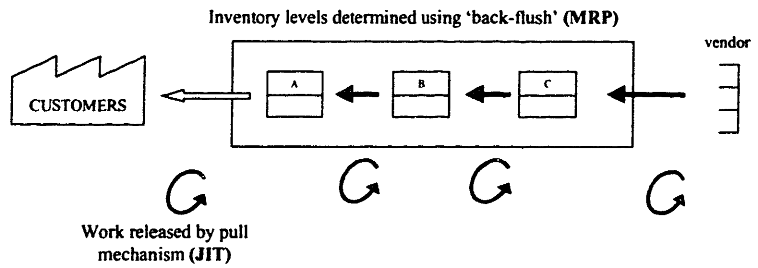

Figure 3. JIT-MRP

Tandem Push Pull - In this hybrid system, the purchase planning lead times are long and are therefore handled by MRP. However, the build routines are based on Kanban. Consequently, the assembly is run on pull and is characterized by great flexibility and short cycles. Whenever the floor's schedule changes, the MRP databases are updated to reflect this (Karmkar 1989, 9). Tandem Push Pull is shown in figure 4.

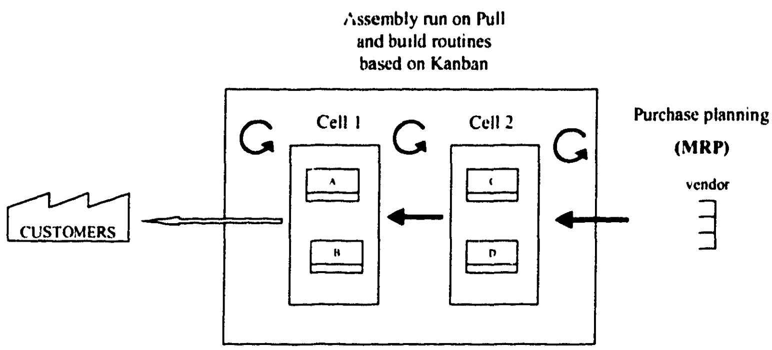

Fig. 4 How MRP and Kanban relate to Tandem Push Pull

Requirement Driven Kanban - In this hybrid system, the entire shop floor is run on a cellular arrangement. It can therefore meet the highly variable and fast schedules demanded by parts with an unstable volume and mix. MRP is suitable for predicting the demand and therefore determining the work to be processed in the various cells. Due to the cellular arrangement that initiates production by pull, the MRP has no order releases and therefore doesn't have to monitor the inventory level in the cell or match the demand with the available inventories. (Karmakar 1989, 9) Requirement Driven Kanban is shown in figure 5.

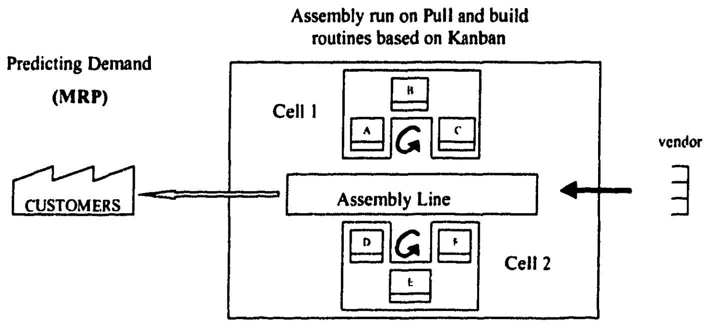

Fig. 5 How MRP and Kanban relate to requirement driven Kanban

Chapter 5 - Case study of Company X

5.1 Background of company X.

Company X is a global leader in the production of centrifuges for use in laboratories worldwide. It has been in existence for close to 100 years and over this period it has concentrated on building a variety of products to meet customers' laboratory needs. It has also pioneered several technologies during this period. X is an ISO 9000 certified company and also meets several standards for companies dealing in centrifuges (IEC 1010-2-020, CE Mark, CSA). X's supplier base has been approved on the basis of its past performance and the current operating systems. This has enabled the establishment of a vendor certification program that ensures delivery of quality parts to X. Company X is a wholly owned subsidiary of a larger scientific equipment manufacturer with annual revenues of about $ 400 million. The parent company handles some aspects of distribution and development for X. In addition to doing direct sales and using its parent company's sales network, company X also distributes its products through Fisher Scientific International, the world's leader in distributing scientific products. Fisher serves about 250 000 customers and boasted sales of $2.47 billion in 1999. Fisher uses a direct sales force and customer-service organization consisting over 2,600 technicians as well as a 2500 page catalog and a website that hosts a digital version of the catalog with real time information. These three distribution networks form the basis of company X's forecasting function.

5.1.1 What do they make?

Company X's primary product line is centrifuges. As of January 2000, it offered 36 different models broadly categorized into a table-top version and a floor based version. A typical centrifuge has about 200 different components (this value was reduced from 300 mainly due to design improvements) with some of these components being interchangeable between models. In addition to complete centrifuges, company X also sells centrifuge accessories such as rotors, buckets, adapters, heating jackets, tubes and carriers. Collectively, these accessories constitute 316 different parts with over one third of them being rotors. For each major piece of equipment, company X uses a serial number to monitor its motion through all the stages of the manufacturing cycle by using markings, labeling and accompanying documentation.

5.1.2 Who are their customers?

Company X has two categories of customers. The first is the US government which can be categorized as a single large customer that deals directly with company X and offers predictable forecasts. The second customer constitutes individuals and scientific institutions who place their orders with company X. Through its Fisher representatives, company X 's sales force also deals indirectly with customers. The prices for the items sold by company X range from less than $10 for some components to as much as $10 000 for a complete centrifuge. All orders are handled through the sales department which then creates the demand for the manufacturing department.

5.1.3 How long have they been using MRP and what did they have before?

Company X has had its manufacturing system set up for close to one century but it's not until 1991 that they started running an MRP based system. Immediately before this, they used a card system to control their manufacturing process. These cards had different types of information such as lot purchasing details, the vendors involved in securing a part and the part number. These cards were stored in alphabetical order at a central location on the plant floor and they never traveled with the parts as they went through the various processes. There were three copies of each card with the first being maintained at the central location and the second being kept by a receiver. In addition to handling the cards, the receiver was also responsible for travelling with the raw material. The information generated in the system was usually run on computers and stored in the form of punched cards that were processed near the company premises.

5.1.4 Are they making any attempts to integrate with lean?

Company X has recently embarked on efforts to make its system lean. They already have a version of cellular manufacturing at the assembly stage of production although the cells do not operate strictly on the principles of lean manufacturing. Another area they have worked on is the reduction of inventory. This inventory has been halved from about 6 million to 3 million parts over the last 3 years. The company has the potential to convert its system from MRP to lean and there are several part families that would easily be used for a pilot study.

5.2 Description of Company X's MRP II system based on one product line

The MRP system at company X was analyzed by studying the manufacturing processes for the base plate (part A) that goes into one of the table-top centrifuge models (model B). The model B centrifuge comes in twenty-two different specifications based on the operating voltage and the type of rotor used. As mentioned before, the centrifuge would has close to 200 different components including part A. When fully assembled it weighs about 11kg and has dimensions of about (30-60cm height, 35cm width and 40 cm depth).

5.2.1 Product types and sizes

Part A is made of aluminum and arrives at the shop floor in its cast form. It subsequently undergoes 5 different manufacturing processes before it is used in the final process of assembling model B. Part A moves in lot sizes of 125 pieces. A stack of these pieces can be seen in the attached photos in appendix 2. A planner work order accompanies each lot and every time an operation is completed, the machine operator signs off. The machines at the various workstations are arranged in a departmental format. Part A consequently has to travel a lot as it moves between workstations.

5.2.2 Value stream of part A and model B from forecast to shipping

The value stream for part A shows the various stages it goes through from the moment it is received from the vendor to the stage when it is assembled into the model B centrifuge. This information is presented in figure 6 which shows the value stream for part A as it goes through the different workstations on the shop floor. The information flow is also indicated.

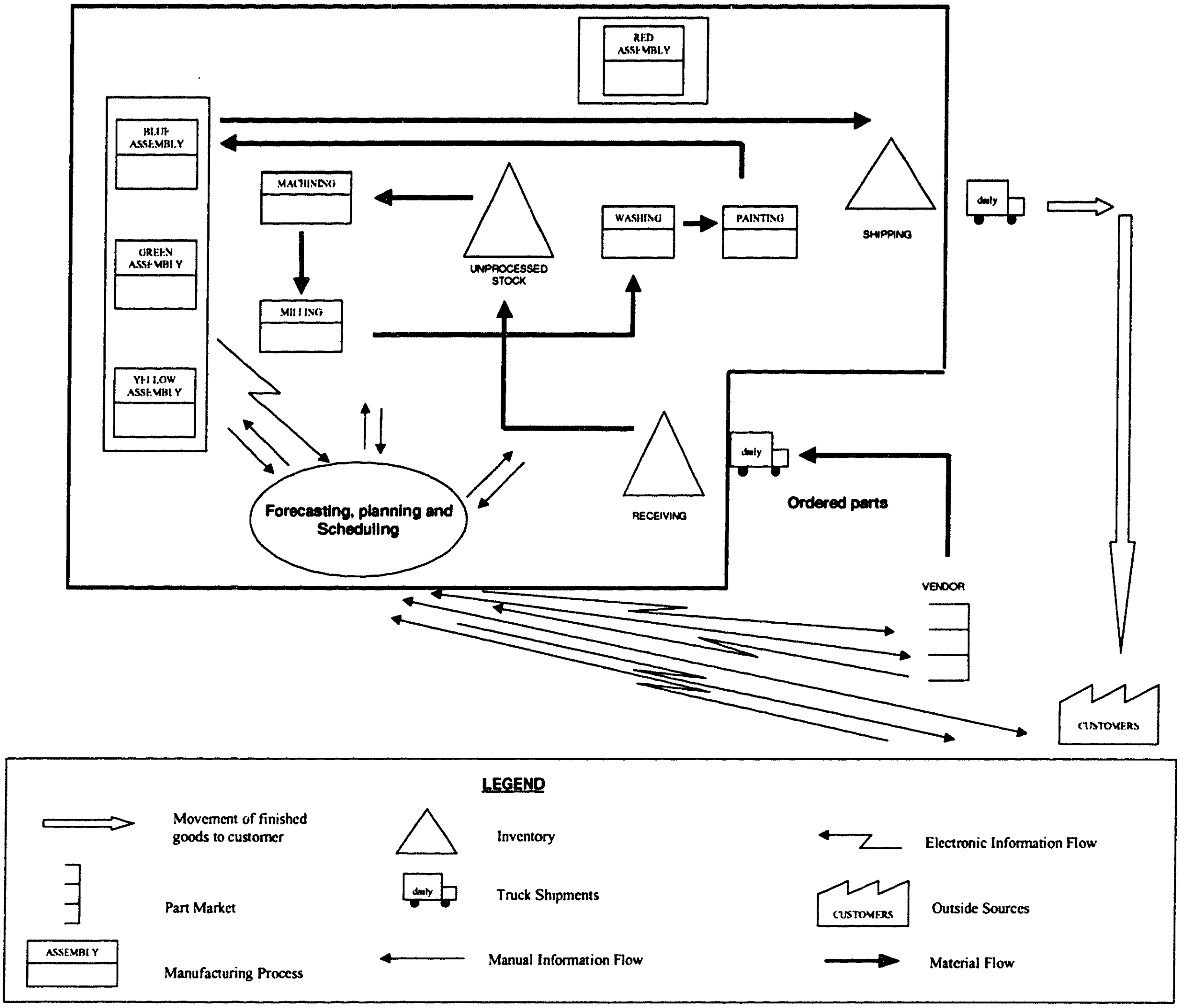

Figure 6. Value Stream of part A of the Model B centrifuge

1. Purchase based on forecasts

The first step involves the purchase of the cast aluminum parts. These parts are obtained from the vendors by the buyers based on information received from the planners. The plans are developed based on the projected forecast of demand. At company X, the planners spend about 4hrs every 3 weeks doing long term plans and 4 hours a day re-planning and doing shorter term planning. Currently one planner is shared by several buyers but company X would like a system where each buyer is assigned their own planner. This relationship is summarized in the flow map shown in figure 7.

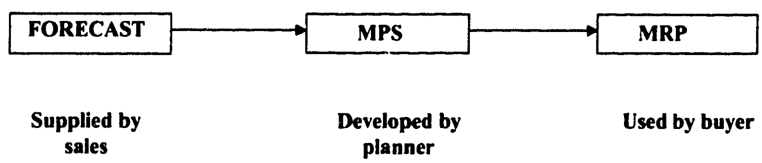

Figure 7. Relationship between Forecasts, the MPS and the MRP modules at company X.

The biggest problem facing company X right now is that the Forecast and MPS modules do not run the MRP module and hence the system is never in control. This problem is characteristic of push systems and particularly MRP as pointed out by Cochran in chapter 4. Company X has a 'Dock-to-Stock' time (the time interval between the arrival of the ordered part at the dock and its arrival at the first workstation for processing) of 1 day. All the inventory representing received stock is housed in one central section near the section of the shop floor that contains the various machines. There is usually a turnover of one month but some of the pieces have as much as a 6 month turnover. Order preparation by the buyer takes about 5 days. The sales team works with an average lead time of 14 days and therefore promise customers a delivery time of two weeks from the time they receive an order for a model B centrifuge. However, manufacturing works with a lead time of about 60 days which in reality reduces to 30-45 days. For the rest of this analysis I shall use the sales lead time of 14 days.

2. Machining

The first process involves turning part A on a lathe until it achieves the desired dimensions. The process uses an automated puma 10 Daewoo machine which is manned by a worker at all times. The entire lot of 125 parts takes up a total of 18.625 hours at the work station. This time includes a set up time of 3 hours and a run time of 0.125 hours per part.

3. Milling

The second process is a milling operation during which holes are drilled in part A and certain sections are milled to their finished quality. The process uses an automated Hitachi Seiko HC 500 machine which is also manned by a worker. The lot takes 55.5 hours to be processed which includes a 3 hour set up time and a run time of 0.42 hours per part.

Before part A proceeds to the next process, a small metallic bracket is fixed onto the milled part using a small portable rivet gun that is located on one of the worker's tables. The time taken is negligible and is therefore ignored in this analysis.

4. Washing

This process uses a large industrial size Typhoon Proceco washer. Since it operates as a batch process, it is possible to handle more than 125 pieces at a go. This process has no set up time. Therefore the entire lot takes 2.4 hours, which roughly translates into a runtime of 0.0192 hours per part.

5. Pre-finish

This process includes all the steps that have to be taken to prepare for painting. The run time is 0.06365 hours which translates into a processing time of 7.95625 hours.

6. Painting

Part A is spray painted by hand in special booths. Several booths lie adjacent to each other and the process just requires the lot to be wheeled to one of these booths. A worker manning the booth uses a spray gun to paint each part individually. There is no set up time for this process but the run time for each part is 0.0926 hours translating into a total processing time of 11.575 hours for the entire lot. Usually the parts are heated so as to reduce the drying time. When there is not enough capacity at company X, outside vendors are sometimes used to do the painting.

7. Assembly

Once part A has been painted, it is delivered to the assembly area. There are 4 different assembly cells at company X. Each cell handles a different family of centrifuges and they are color coded as follows: yellow (large floor models), green (refrigerated and non-refrigerated models), red (large table top models) and blue (small non-refrigerated models). Model B is assembled in the blue cell. The assembly process is done in four steps. During all the stages, each centrifuge is accompanied by an inspection sheet that indicates any problems that are encountered during assembly. In the first step the base is assembled. This is the stage where part A is incorporated into the centrifuge. In refrigerated models, the refrigeration unit would be added next but this step is not necessary for model B. Next, the cabinet that forms the centrifuge housing is added followed by the transformer for voltage conversion. The final step involves testing the centrifuge for performance. Centrifuges that pass the test are packaged and sent to the shipping dock ready for delivery to the customer.

In case problems are encountered for a given part during assembly, the workers will try to resolve it themselves. If that fails, the part will be put aside and the manufacturing or design engineers will be called in to rectify the problem. This ensures uninterrupted production. The manufacturing engineer is also responsible for obtaining feedback from the workers in the cell and using that information to effect the necessary changes. The workers in the assembly cell are cross-functional and can consequently cover for a missing worker. However they remain tied to one assembly process in the cell at all times. It takes about one week to train a new worker. To facilitate this, a folder containing information about the assembly process is kept at the cell. Also within the cell is a computer terminal that is used to enter information into the MRP system. Typically, each worker will update the records every time they finish working on a part.

8. Shipping and Delivery

Parts are shipped and delivered on a daily basis. UPS makes deliveries in the morning and collects shipments in the afternoon. They pick up all the items that they find at the shipping dock and deliver them to the various locations based on the information provided by the sales office.

5.2.3 The MRP Process at company X

The MRP system at company X is designed to meet the demand for the finished product while minimizing inventory. It therefore has the role of determining the levels of intermediate good inventories needed to ensure that the finished product demand will be met. This premise is what has led to the design shown in figure 7. As mentioned before the sales forecasts and the MPS module at company X do not run the MRP module. Typically when new orders are received, they tend to use up all the forecast parts.

The MRP system at company X is based on the Glovia ERP system produced by Miracle Information Systems of the UK. The Glovia system incorporates both client/server technologies and object oriented standards. Company X has a modular system with financial, sales and operation modules. It runs on Windows and uses an Alpha Server system with an Oracle database. Company X made the upgrade to Windows in mid 1999. This is an example of how companies normally solve MRP problems through software improvements as discussed in Chapter 2. The operations module is further subdivided into three parts: Inventory Management, Master Production scheduling and Material Requirements Planning. This module integrates closely with the sales module and it provides data to the financial side. The following is a description of the key parts of the MRP system designed by Glovia showing how control is effected on the shop floor. This information is based on appendix 3 which shows the various interfaces of company X's MRP system, a purchase order form, an exception report, the schedule of one of the cells and a work order.

Options and Location Table

There are two versions of this table, one for the MPS module (version i) and the other for the MRP module (version ii). Both versions indicate if there is inventory on hand.

The MPS module has a planning horizon of 365 days and a review time of (time bucket) of 7 days. An increase in stock is indicated as a replenishment while a decrease is noted as a requirement. Replenishment of the MPS is carried out using five documents; Purchase Order (PO), Computer Planned Order (CO), Work Order (WO), Forecast Planned Order (FPO) and Supplier (Sup). Requirements of the MPS are determined by four documents: Forecast (Fcst), Sales Order (SO), Forecast Planned Order (FPO) and Demand (Dem). Version i also indicates whether or not the forecast of demand has been used. It indicates when the MPS regeneration was done and indicates the person responsible.

The MRP module also has a planning horizon of 365 days but it has a time bucket of 14 days. The documents that determine replenishment of the MRP are identical to those of the MPS with the exception of the Computer Planned Order (CO). The documents for determining requirements are identical to those of the MPS.

MRP/MPS Planning Detail Inquiry

This table is used in netting so as to determine if there is sufficient material to meet the demand. It offsets the requirements from the replenishments to give the net number of items available. In addition it gives a reference number for the item(s) in question, the delivery date of the replenishments, the due date of the requirements and the quantity of each desired. The attached tables show the netting calculations for the model B centrifuge (version iii) and a component (part C) of the centrifuge, which is not the same as the aluminum base studied earlier (version iv).

Version iii uses the sales order and the forecasts to determine the requirements. Note that the net available stock for this case is always a negative value meaning that the shop floor is short of material. This is a characteristic of MRP that results form its effort minimize inventory such that material from the vendors is held back until the last possible moment.

Version iv uses the work order, the MPS and forecasts to determine requirements and purchase orders to do replenishments. Note that there is initially a net positive amount of stock as of the 10^{th} of February but this quantity gradually declines to a negative value on the 7^{th} of March as requirements are met. The first replenishment is not made for another 14 transactions until the 17^{th} of March when an order for 135 pieces of part C are made. However the stock remains negative until the 6^{th} of April when the second replenishment is made. The remaining appendices show copies of the purchase order form, the MRP exception report, the schedule for the red cell and a work order form. Note that the exception report is typically eighty pages long and the sheet shown is from page 44.

5.3 General observations

There was a lot of inventory observed on the shop floor. The large amount of inventory was attributed to several factors. For example, there was a section on the shop floor that was dedicated to handling faulty parts. This area was called the Material Review Board (see Fig 17 in Appendix 2). From here parts were sent to the various workstations to be reworked or otherwise they were labeled with a red tag to be shipped back to the vendor. In another instance, a certain type of aluminum casting was still at the plant having been ordered almost 12 years ago in 1988. Since orders were still received for the part, the stock could not be discarded but since the model of centrifuge for which the part was used had been discontinued, the part was left to lie idle. In a different instance, a functional part that was completed in 1998 was still lying around because it was produced in error and had actually not been needed when it was made.

Company X does not pay attention to the capacity of the plant. Although a detailed capacity planning module that tells what the actual situation on the shop floor exists, it is not used. Instead they use an excel spreadsheet that is updated frequently to assign jobs to the various machines. This was pointed out in chapter 2 as one of the weaknesses of MRP system.

In spite of company X doing their planning a month ahead, it was noted that the mix of orders placed wasn't usually met. However, their sales targets were often successfully met. This inaccuracy shows that the MRP system does a bad job of leveling the orders and this can be attributed to the large lot sizes and the long throughput time.

In summary, company X's MRP system did not work very well because it had to deal with the randomness of the shop floor. To do this, it needed certain conditions to exist on the shop floor, which wasn't necessarily the case at company X i.e.: A large backlog, excellent forecasts, vendors who didn't miss quality targets, vendors who kept to schedule, existence of large inventories and short material lead times. These can easily be correlated to the various constraints highlighted using the decomposition in chapter 4.

Company X should try to establish a lean system on its shop floor. Based on the solutions suggested by Uday Karmakar in Chapter 2, company X could try implementing a

'Tandem Push-Pull system' or a 'Requirements driven Kanban' system. A proposed design that meets the requirements of a lean system is discussed later in the chapter. The infrastructure to enable this transition currently exists. A pilot cell can be based on a family of centrifuges for example those assembled at the blue cell.

The throughput time of part A is very high mostly as a result of lot delays and the long setup times. Based on the processing and setup times provided, the throughput time is 96.05625 hours (about 4 days). This does not take into account transport delay or machine downtime. The actual value adding time is less than an hour (0.72045hr). This could have been predicted by the analysis provided in chapter 4 using the Manufacturing System Design Decomposition. This information is shown in figure 5. This delay is clearly illustrated in figure 8 which compares the delay processing time for a run size of one and a run size of 125.

The performance of the MRP system at company X can be illustrated using the following real life data for a part A order. On February 10th, an order was opened for 136 bases. By the time the order was closed on April 6th, 132 bases had been completed and 4 remained. Starting April 14th, the parts started being used in the assembly process.

5.4 New and improved value stream map with linked cell system

A new and improved design for company X's shop floor is presented in figure 9. In the lean design with linked cells, the plant floor is divided into three main processing areas. There is a set of cells that carry out the primary processing of part A i.e. milling and turning on a lathe. In this area, there are four almost identical sets of machines that contain either two mills and a lathe or two lathes and a mill. Before and after each of these machines, there exists a decoupler where the unprocessed / processed part is placed

	(1) Lot size of 125	(2) Lot size of 1
set up time (hrs)	3	3
machining (hrs)	15.625	0.125
set up time (hrs)	3	3
milling (hrs)	52.5	0.42
washing (hrs)	2.4	0.0192
pre-finish (hrs)	7.95625	0.06365
painting (hrs)	11.575	0.0926

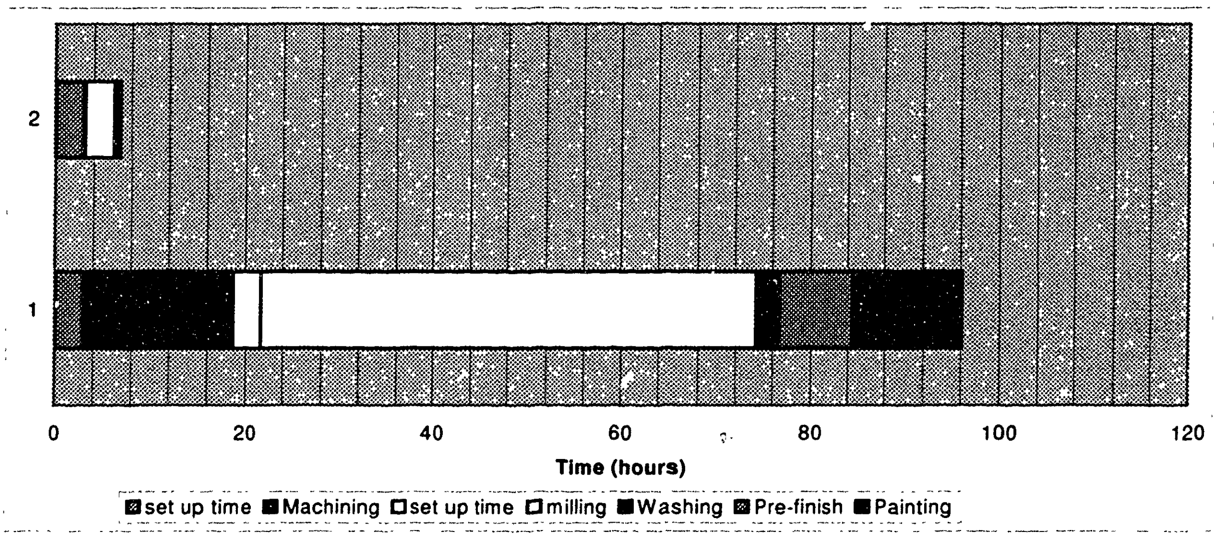

Figure 8. Excel Spreadsheet showing the delay introduced into the system due to the large lot size (125 parts) compared to a lot size of 1 part.

in between cycles. When a part is placed on the decoupler located after one of the milling machines, the metal bracket that was described earlier in the chapter can be fixed as the part waits on the decoupler before it's next process. The cell cycle time for this area will be determined by the slowest machine (or the longest process to be done on part A which in this case would be the milling operation). Since all the machines would be running in parallel, a complete part would be produced from the cell after each cycle time.

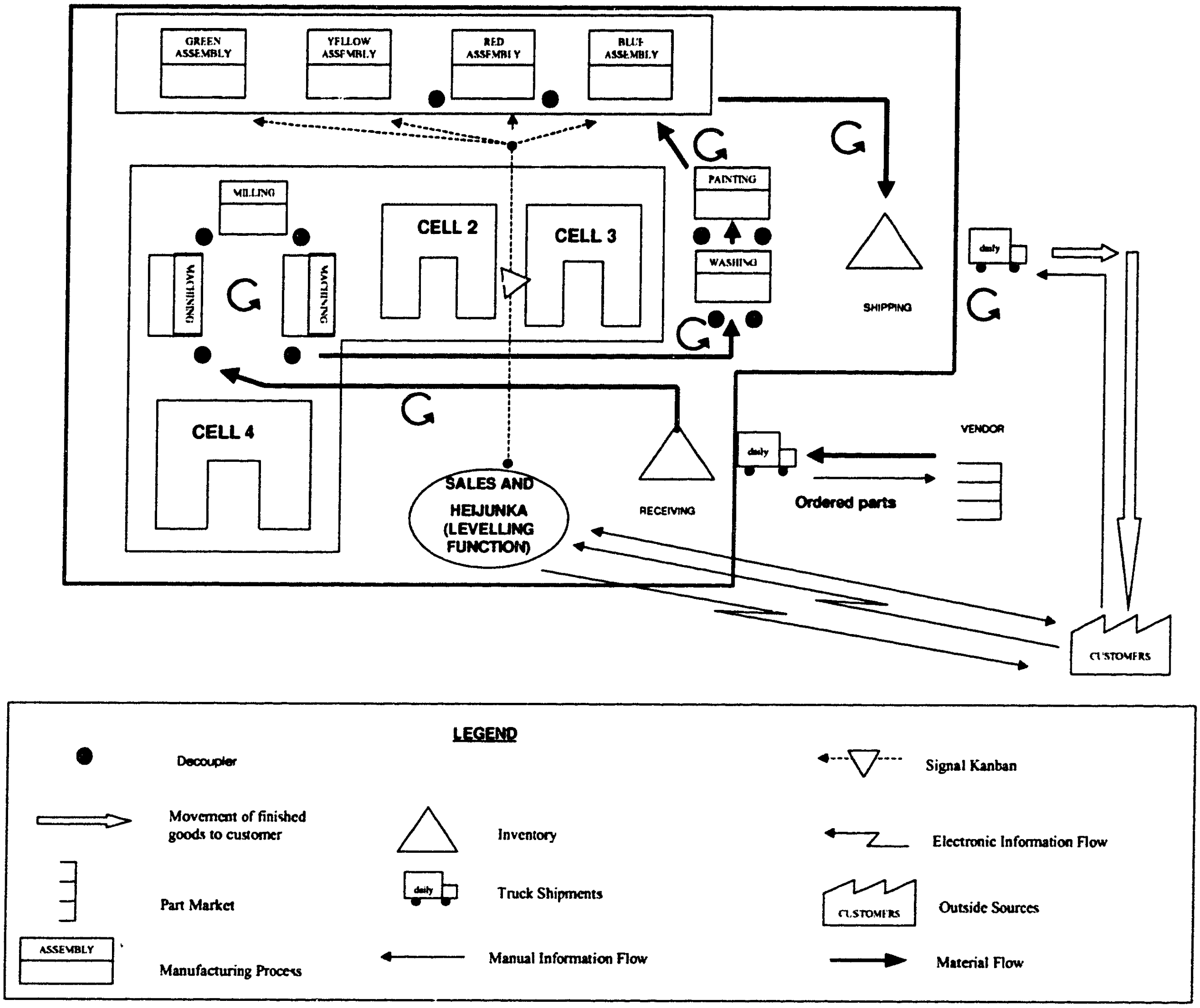

Figure 9. New and improved value stream map with linked cell system

The second area constitutes the washing process and the painting process. Sincere there is only one washer available and it has a large capacity, the parts can be brought to it in given batch sizes that ensure downstream processes are not kept waiting. Given the small processing time for the washer, this process can easily be coordinated to match the cycle time in the previous and subsequent cells. The part from the previous cell is carried from the last decoupler and taken to the decoupler next to the washer where other parts from the other cells on the shop floor are also assembled so as to build up volume. An ideal washer design would use a conveyer belt such that the part never has to wait on other parts in order to get processed.

The third area is the assembly area. This area would have all the four cells (blue, red, green and yellow). Parts coming from the washer would be placed on the appropriate decoupler in each of these cells. As soon as a part is pulled out of the cell to shipping, the part coming in from the washer would go into the cell and be assembled into the centrifuge. Company x currently has these cells set up and the only challenge would be to design their location so as to minimize transport time to the shipping dock.

The information system would work as follows. A customer would make an order to the sales office which would then coordinate with the manufacturing department to provide the right mix and volume of parts to meet the demand of the various customers for a given day. The customer can give this information electronically through the web based system discussed earlier in the chapter or using regular purchase order forms sent directly to company X. The 'heijunka' is a system that carries out the role of distributing demand in terms of volume and mix. Information from the 'heijunka' is then communicated to the four assembly cells using a signal kanban which tells the cells what to produce. The four assembly cells pass this information backwards to the washer and painting area and subsequently to the four primary processing cells. In this way production is driven by the customer demand. When the completed part is pulled out of the assembly cell and is sent to shipping, it is picked up daily whenever the delivery services comes by to collect parts to be delivered to the customer. The parts delivered from the vendor are also delivered daily to company X based on parts that have been pulled out of the four primary processing cells. This arrangement ensures that sales targets are met both in terms of mix and volume.

The customer demand can be used to determine the takt time which is simply the total customer demand divided by the available manufacturing time. The goal is to ensure that each of the cells on the shop floor has a cell cycle time that is equal to or less than the takt time. In this way, company X's shop floor will be designed to keep pace with the customer demand. The arrangement in cells has the added advantage that various parts for any of the four centrifuges can be processed at any of the four primary processing cells provided the number of milling or turning operations is known. For processes requiring more than three operations, two cells can be combined to provide more machines for the additional operations. The speed of the cells can be varied by adding or reducing the number of workers operating the cell since they would each be cross-trained to handle any of the machines in their cell. Note that the workers are not tied to a given machine.

Chapter 6 - Conclusions

MRP II is not a very effective method of achieving control on the shop floor. The constraints and limitations that cause this can broadly be divided into seven categories as summarized in the table 1:

Table 1: The Limitations and constraints of MRP II as a tool for shop floor control

Limitation and Constraint	Functional Requirement (FR)	Design Parameter (DP)
Quality	1. Eliminate machine assignable causes 2. Ensure operator human errors do not transfer to defects 3. Eliminate material assignable causes 4. Improve capability of process	1. Selection / maintenance of equipment. 2. Mistake proof operations (Poka-Yoke) 3. Supplier quality program 4. Design of experiments to check for poor capability
Identifying and Resolving Problems	1. Identify disruptions where they occur. 2. Identify disruptions when they occur. 3. Identify nature of disruption 4. Minimize delay in contacting correct support resources. 5. Supply descriptive information to support resources. 6. Solve problems immediately	1. Simplified material flow paths. 2. Increased operator's sampling rate of equipment status. 3. Context sensitive feedback. 4. Rapid Information transfer system 5. System that conveys nature of problem. 6. Standard method to identify and eliminate root cause.
Predictable Output	1. Ensure availability of relevant production information. 2. Do not interrupt production for worker allowances. 3. Ensure material availability.	1. Capable and reliable information system. 2. Mutual Relief system with cross-trained workers. 3. Standard material replenishment system.
Delay Reduction	1. Provide knowledge of demand product mix (part types and quantities) 2. Produce in sufficiently small run sizes. 3. Define takt time. 4. Ensure that production rate is balanced with takt time ($r_s^{max}=1/t_t^{min}$) 5. Ensure that part arrival rate is balanced with service rate ($r_a=r_s$) 6. Reduce lot delay 7. Reduce transportation delay	1. Information flow from downstream customer 2. Design quick changeover for material handling and equipment. 3. Definition or grouping of customers to achieve takt times within an ideal range. 4. Subsystem enabled to meet the desired takt time (design and operation) 5. Arrival of parts at downstream operations according to pitch. 6. Reduction of transportation

		lot size (single-piece-flow) 7. Material flow oriented layout design.
Direct Labor	1. Eliminate operator's waiting on machines. 2. Eliminate wasted motion of operators.	1. Human machine separation. 2. Design of workstations / workloops to facilitate operator tasks.
Indirect Labor	1. Eliminate managerial tasks 2. Eliminate information disruptions	1. Self directed work teams (horizontal organization) 2. Seamless Information flow (visual factory)
Facilities Cost	Minimize facilities cost	Reduction of consumed floor space

The interaction of these various issues causes the frequently observed problems of fixed lead time and infinite capacity. From a systems perspective, MRP can be modeled as an open loop system with a non functional feedback arm. Since information flows downstream, in the same direction as the material flow, the actual reality on the shop floor is different from that conveyed by the information system.

This discrepancy gives rise to the large amounts of inventory often seen on the shop floor and an inability to meet the customer demand.

A good shop floor control system is one that has the goal of developing a dynamic and flexible organization. Its design takes into account the structure of the system and the individual work tasks on the shop floor. This introduces a capacity for self design and lasting adaptability that enables the shop floor control module to become an agile entity that can keep pace with ever changing customer demands. MRP II fails in this respect because of its inability to work well with randomness. It normally thrives well in systems characterized by large backlogs, excellent forecasts, highly reliable vendors, large inventories and short material lead times. Unfortunately, this is not the reality in current production environments.

MRP II 's problems cannot be solved by carrying out small improvements such as software updates. Instead, it calls for radical steps that address the logic behind the entire system. One solution is the use of hybrid systems that complement the push characteristics of MRP with those of pull systems. Pull systems are particularly effective as control modules in manufacturing systems. In this arrangement, MRP can still be utilized as a planning tool to create demand for the production system.

In the case study provided, company X runs an MRP II system that has little control over the shop floor. The system is characterized by large inventories, long delays and an inability to keep up with customer demands using the inventories on the shop floor. Company X nevertheless has an excellent infrastructure for distributing its products and receiving orders. Several of its problems can be solved by shifting its manufacturing system to 'lean'. Using already existing product families of centrifuges, company X can establish cells based on the Tandem Push-Pull hybrid system or the Requirement Driven Kanban system suggested by Karmakar.

The design of a Kanban controlled cell at company X is a potential area for subsequent study. This would involve the design of a cell using the existing machinery to establish a cell cycle time that keeps pace with the customer demand. A second area that needs further study is the value stream mapping for a single centrifuge. This would involve tracking the process of putting together one centrifuge from all its 200 different components (this study looked at only one such component). These two areas would provide the foundation for converting company X's system to lean. Subsequent improvements would address issues such as the size of inventory, reducing set up time for the different machines, Coordinating production to enable throughput time for all the components to equal the actual processing time.

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APPENDIX 1

7 X 11 sheet with a chart showing the Production System Design Decomposition

APPENDIX 2

Fig. 10 Receiving Dock at company X. Note the amount of inventory.

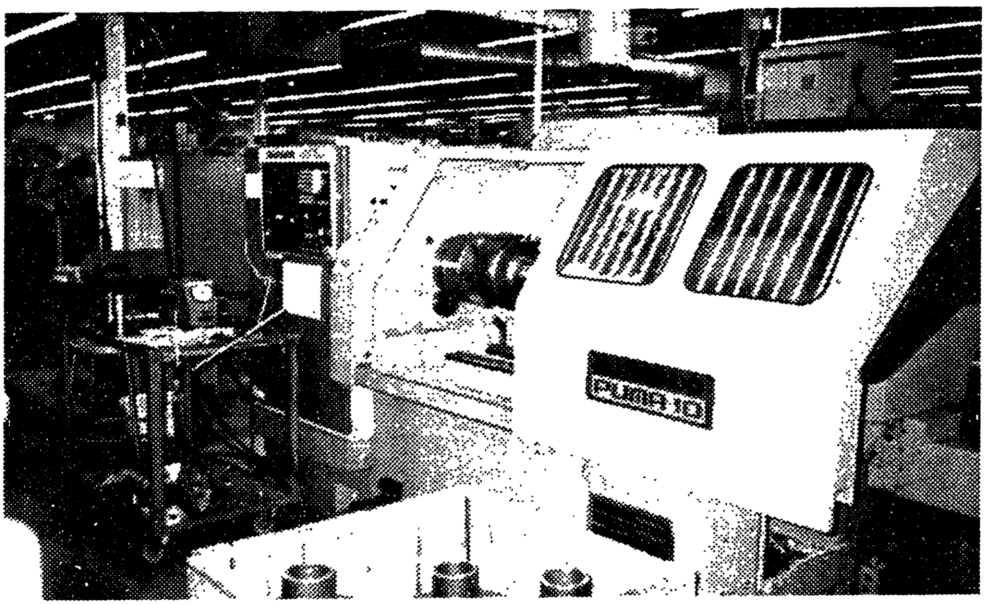


Fig. 11 Puma 10 Daewoo CNC lathe. Note the crate in the foreground containing unprocessed parts.

APPENDIX 2

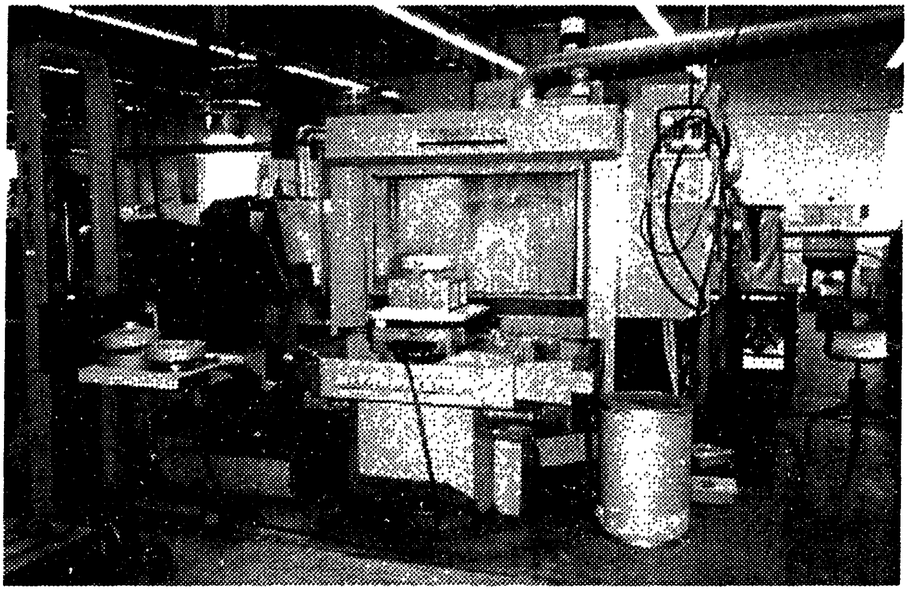


Fig. 12 Hitachi Seiko milling machine

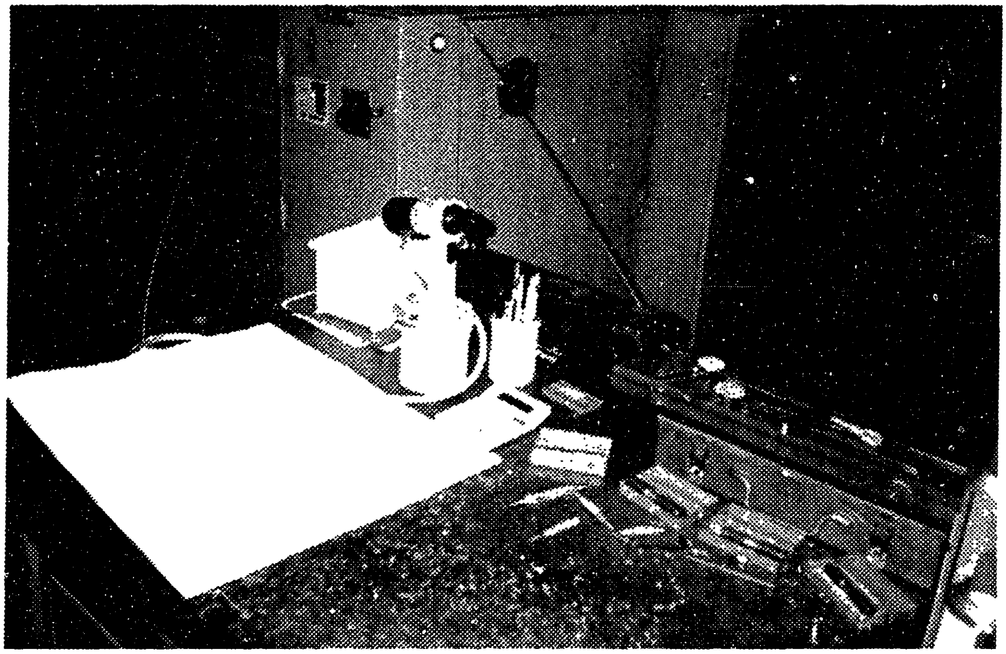


Fig. 13 Portable rivet gun on the worker's desk used for fixing metal brackets onto the milled part.

APPENDIX 2

Fig. 14 Typhoon Proceco washer. The region in the background contains more inventory. (also see fig. 20)

Fig. 15 Painting booth. The spray gun is visible next to the cart on the right.

APPENDIX 2

Fig. 16 Blue assembly cell with a worker at his station. Notice the fully assembled centrifuges to his extreme left. From here parts are shipped to the customer.

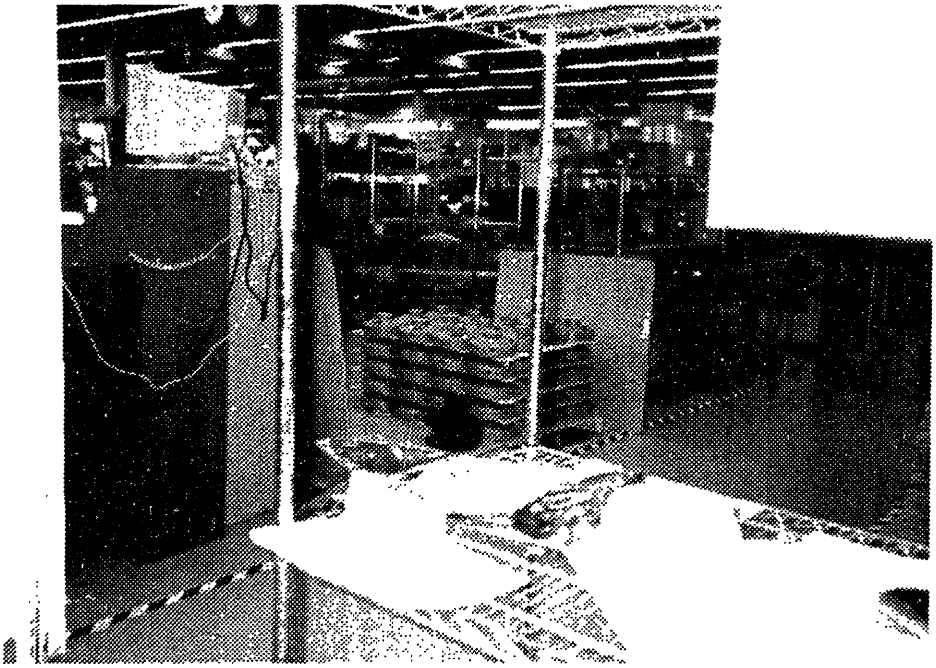


Fig. 17 A different view of the blue cell. The metal shelf in the foreground is the Materials Review Board. On the top left side of the photo is the computer used for to input information from the cell. Note the painted pieces of part A arranged in a stack.

APPENDIX 2

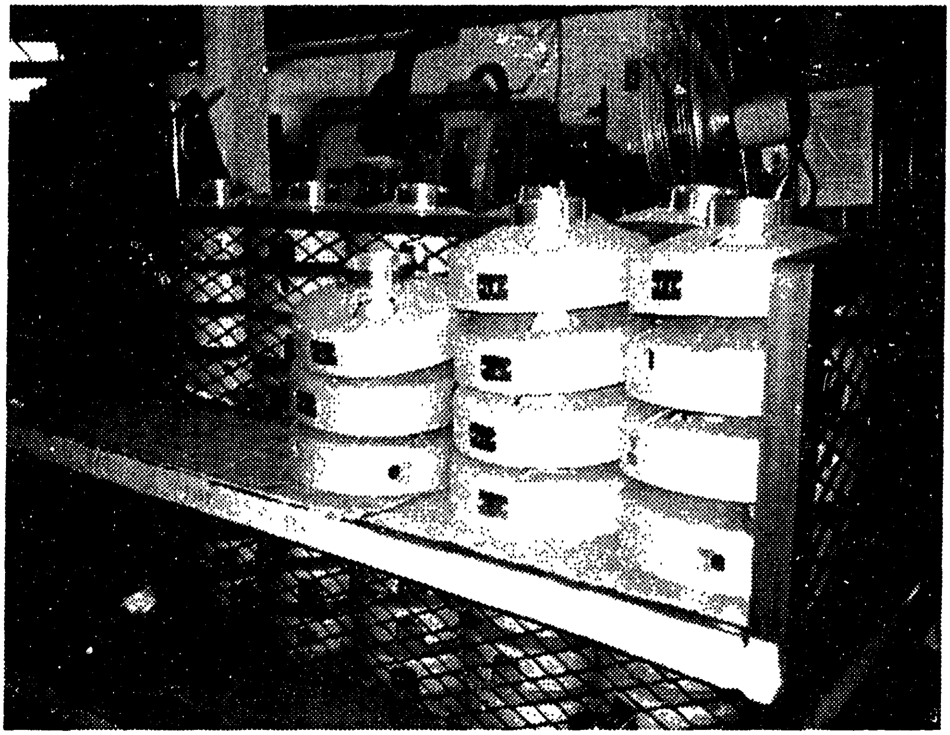


Fig. 18 A lot of part A pieces after machining, milling and fixing of the bracket. Note the amount of inventory.

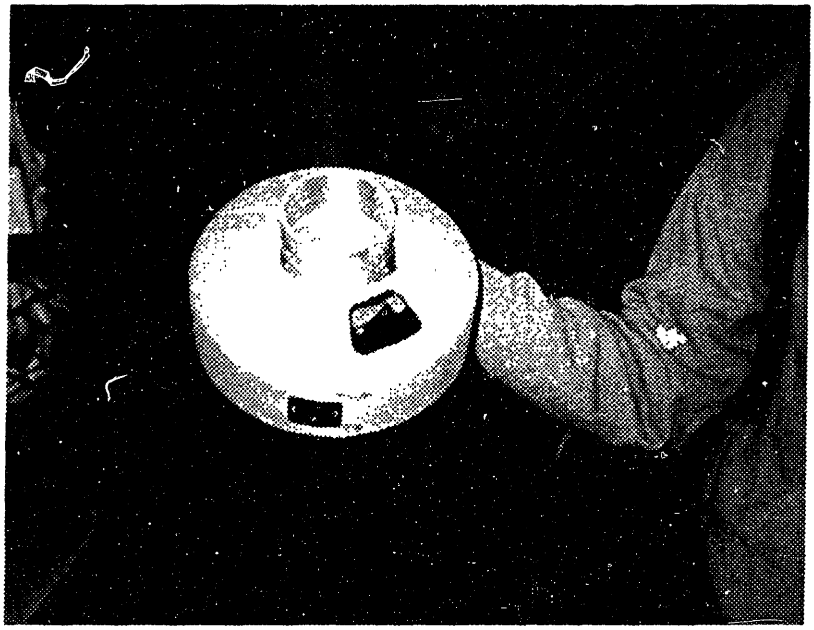


Fig. 19 A closer view of part A

APPENDIX 2

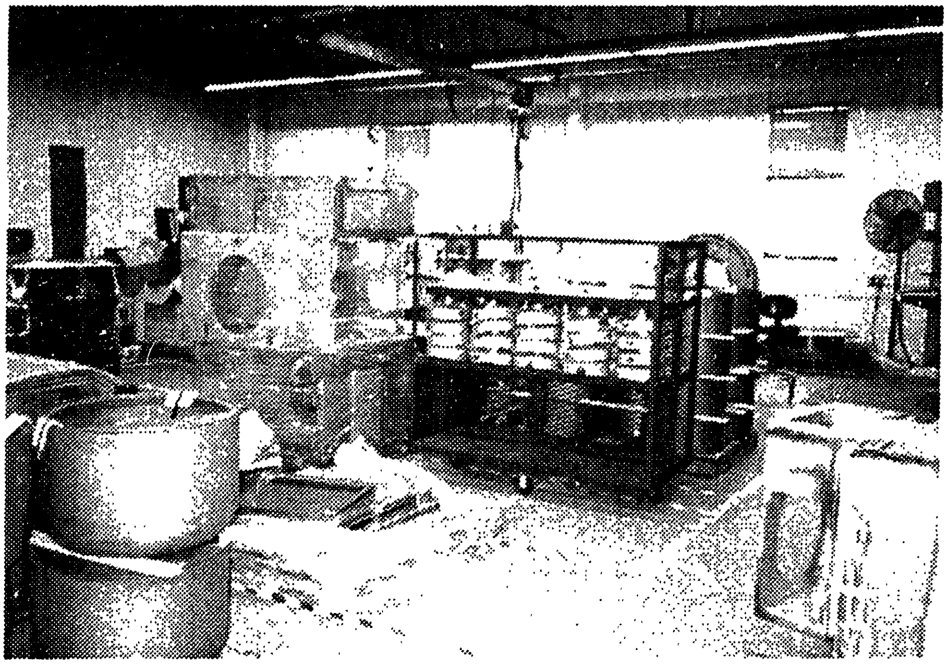


Fig. 20 Inventory on the shop floor. Note the cart containing part A pieces.

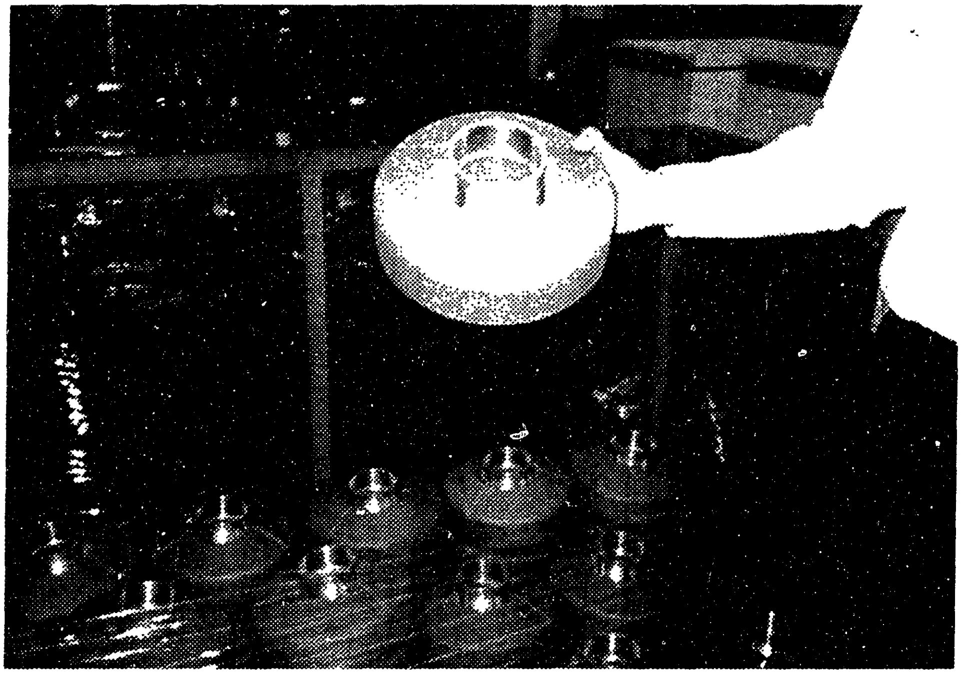
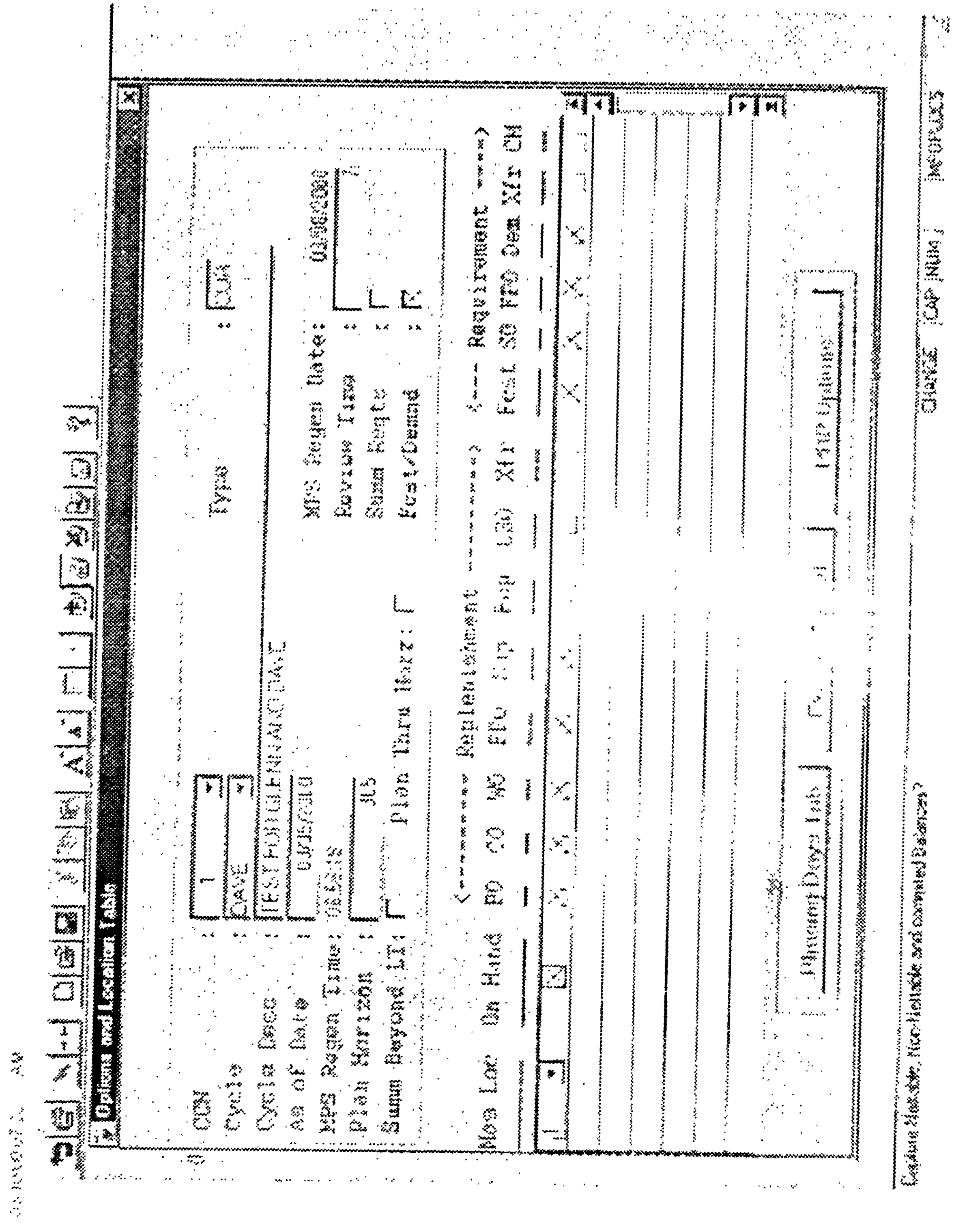


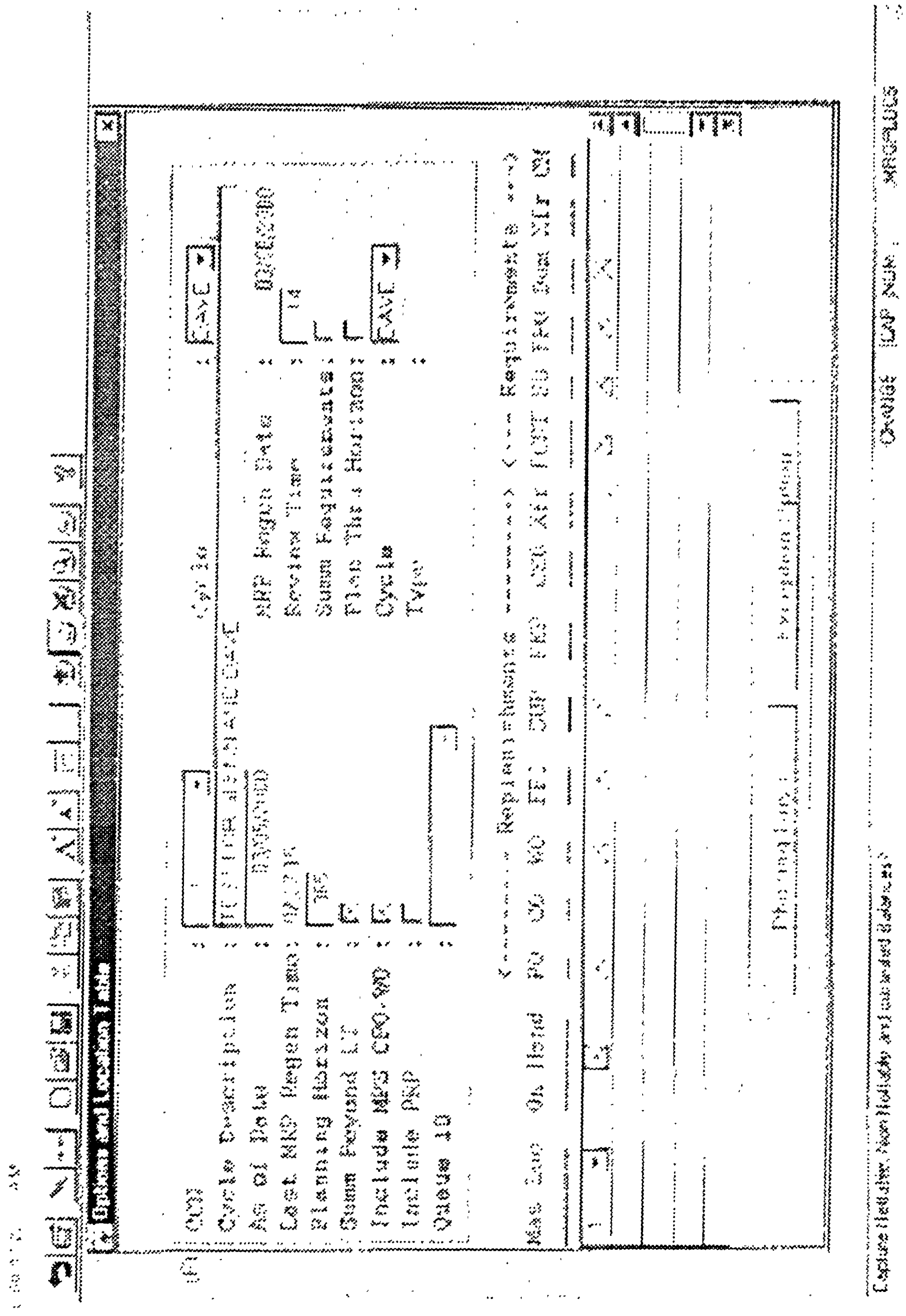
Fig. 21 A view of part A after it has been machined but before it has been milled.

Original
Pages following
have poor text
or
poor pictorial
quality

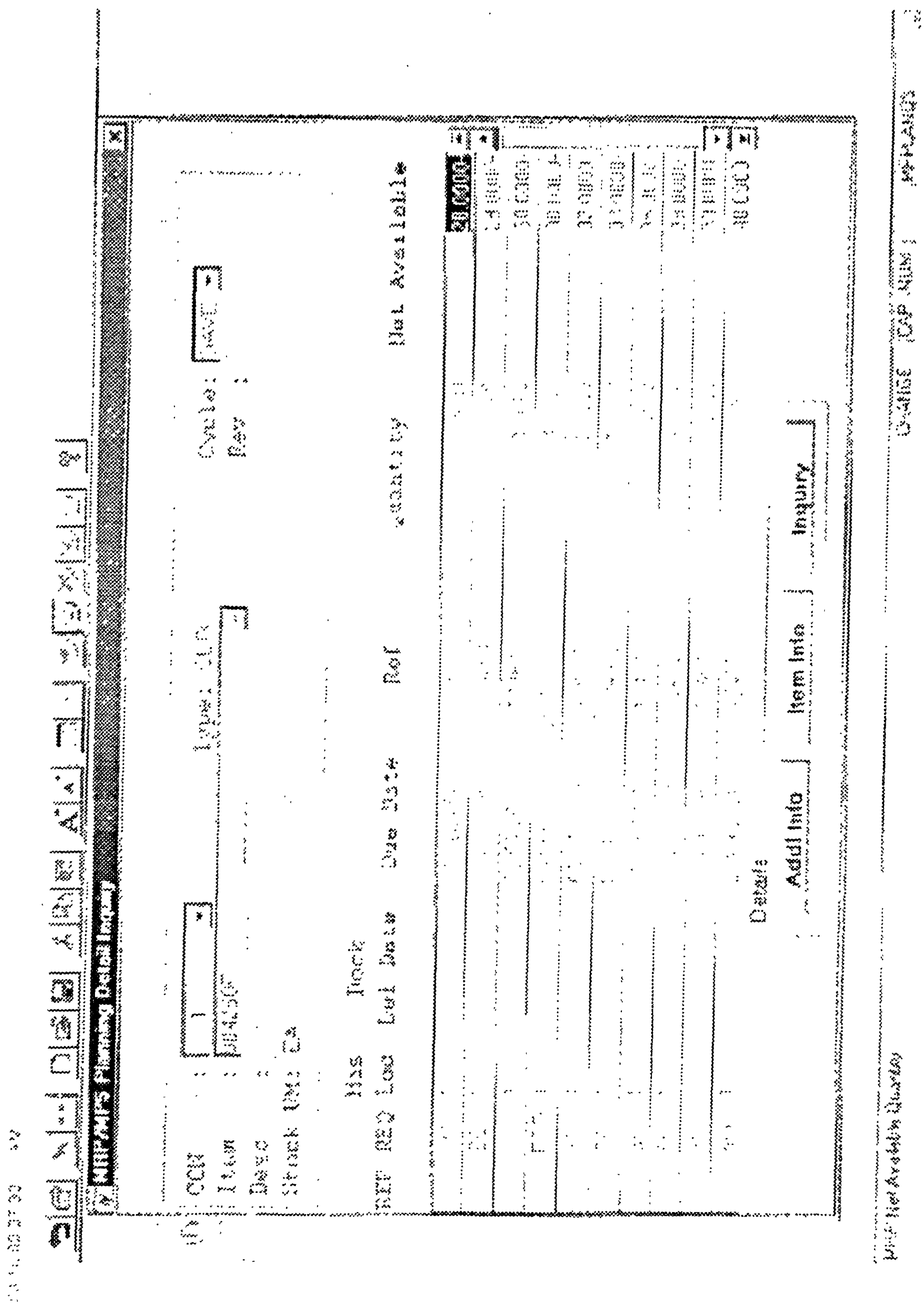
APPENDIX 3 (i)


Options and Location Table
Cycle
Cycle Desc
Type
MPS Regen Date:
Plan Thru Horz:
Replenishment
Requirement
Planning Days Tab
MRP Updates

APPENDIX 3 (ii)



APPENDIX 3 (iii)



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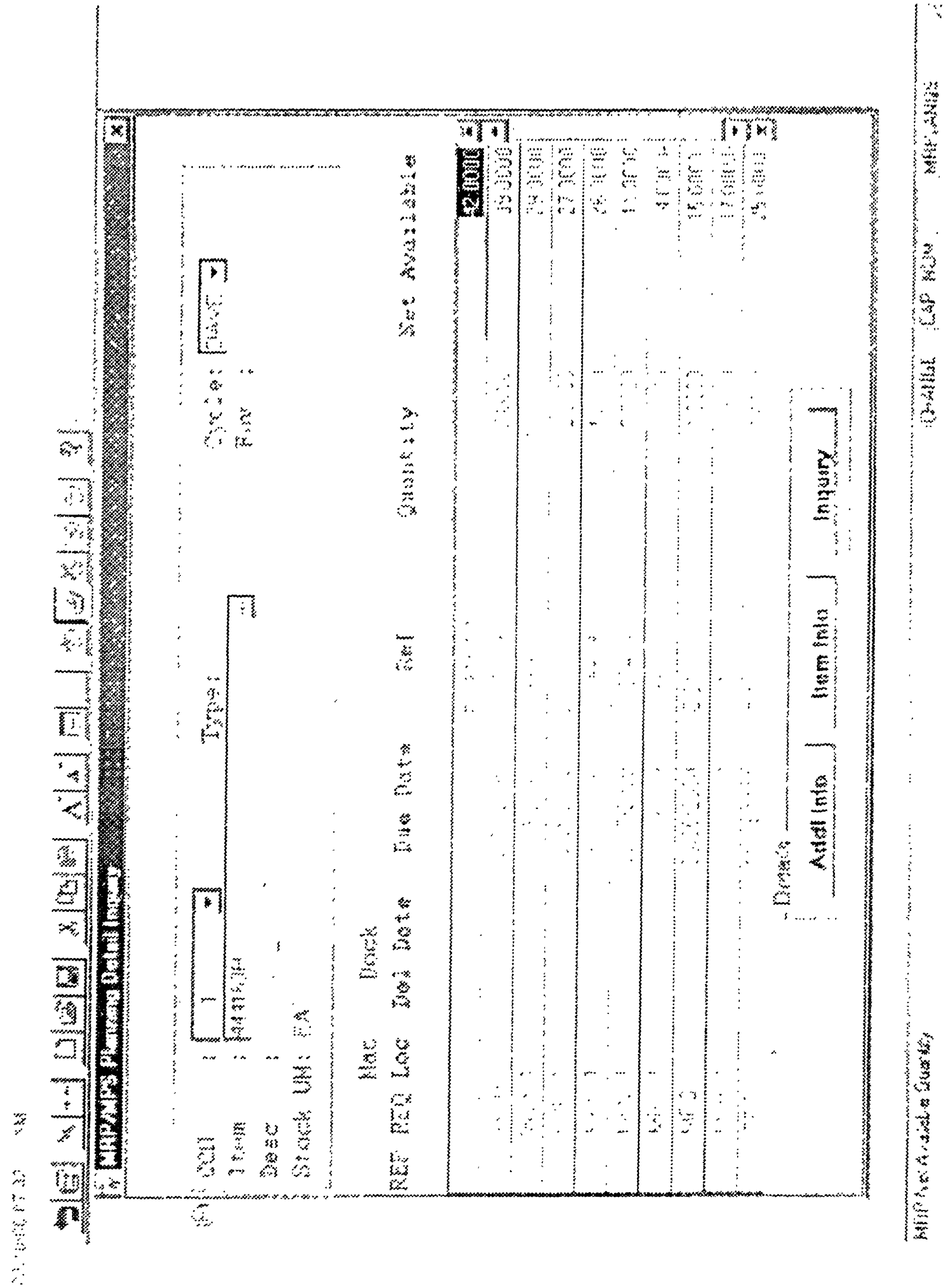

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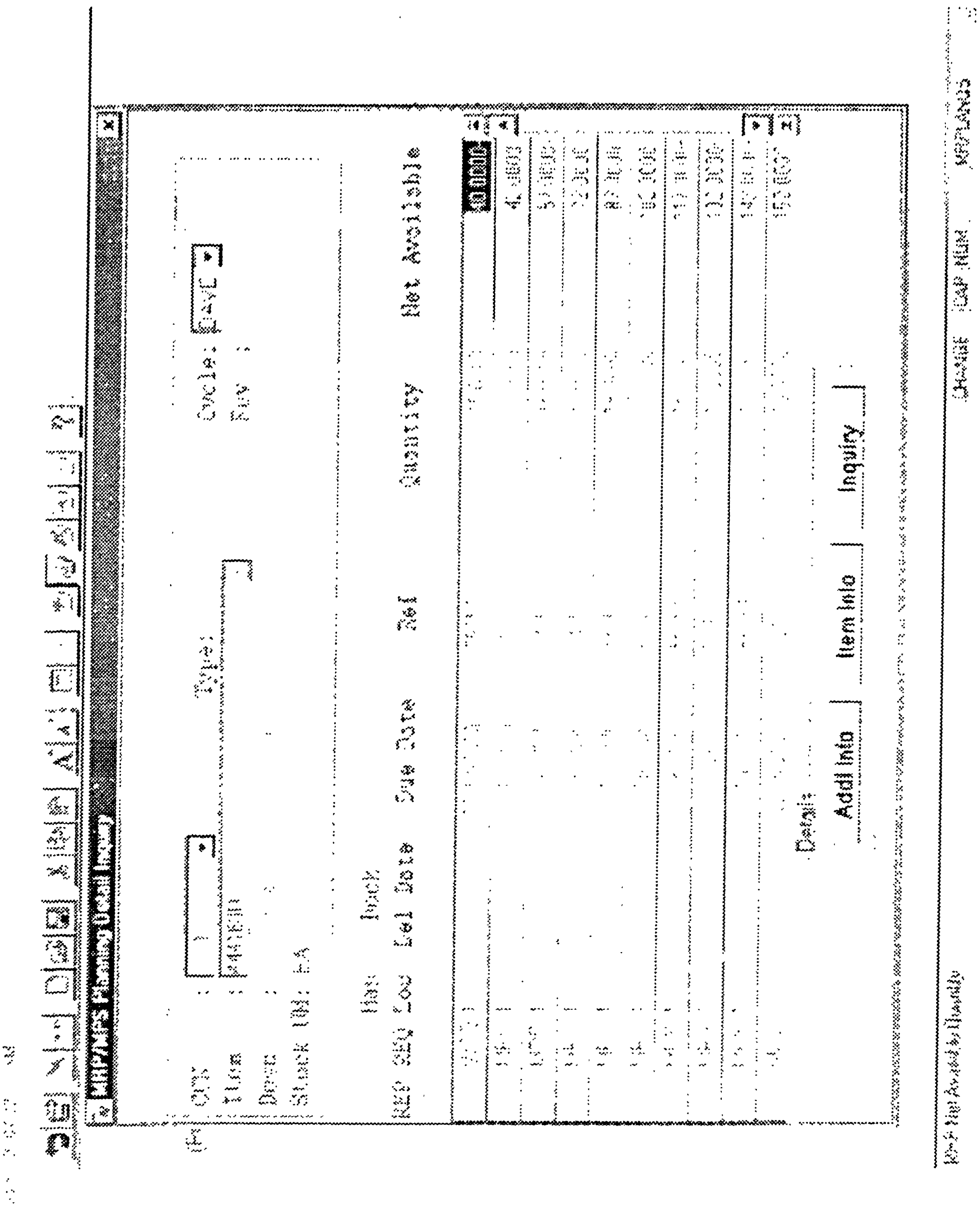
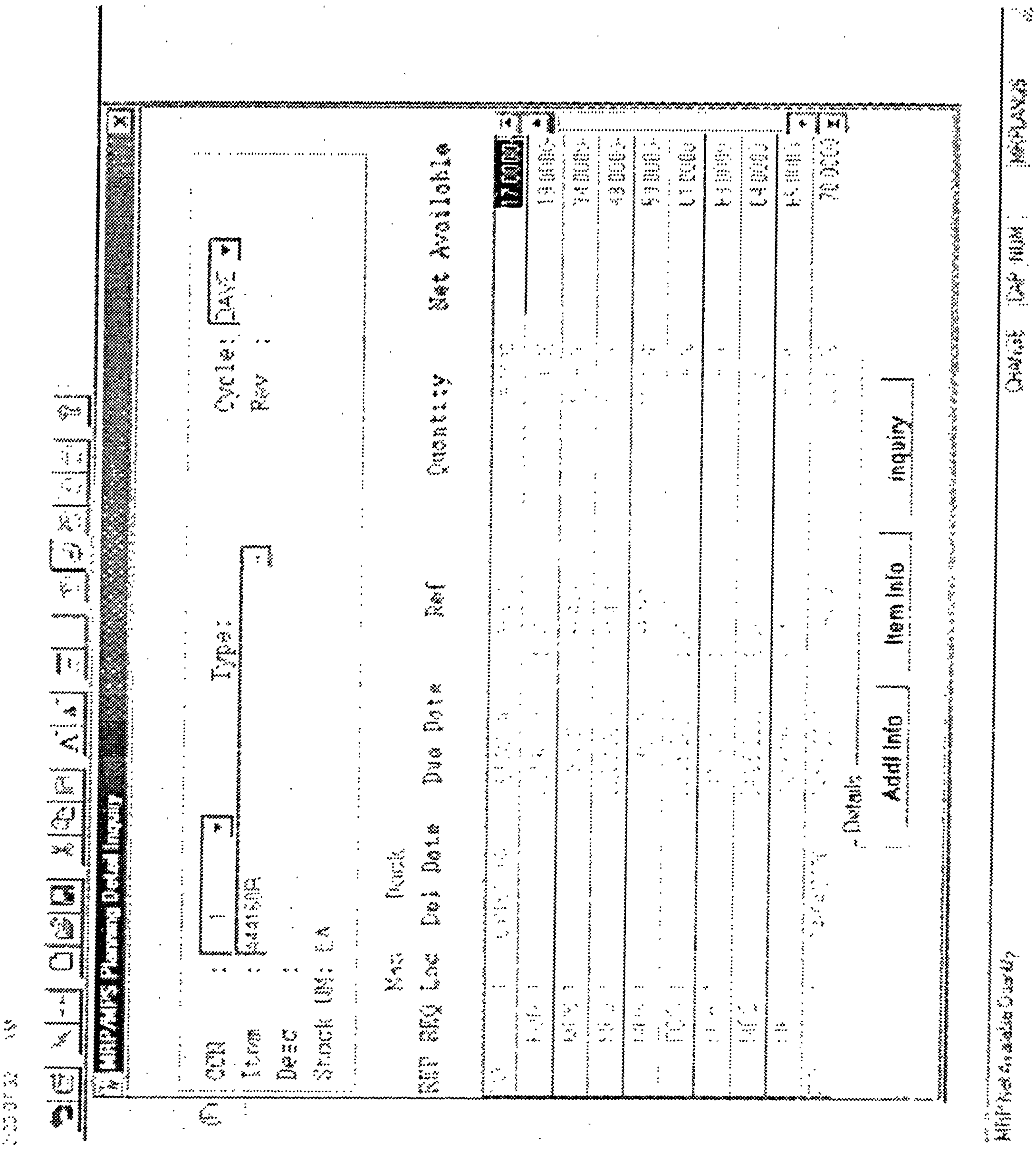

MRP/MPS Planning Detail Inquiry
Type:
Cycle:
Quantity
Not Available
Ref
Due Date
Rel Date
Details
Add Info
Item Info
Inquiry

APPENDIX 3 (vi)



APPENDIX 3 (vii)

Purchase Requisition
03/10/00 08:11:23

CLOSED
SEIBAN :

32908

Page
1

COMPANY X
(ADDRESS)

30180 01 1

VENDOR Y

Invoice To
COMPANY X

Buy Language

Buyer
Bill Young
Terms

Acknowledgement
Not Required

Currency

Delivery Terms Carrier

Line	Item/Vendor Item/Description	Rev	Entry Org/Dispatch	UM	Tax	Quantity	Unit Price	Extension
0001	027820K		400/400	EA		1375.000	[redacted]	[redacted]
	FIELD							

Del No	Del Qty	Del Date
001	125.0000	08/01/2000
002	125.0000	08/29/2000
003	125.0000	10/03/2000
004	125.0000	10/31/2000
005	125.0000	12/05/2000
006	125.0000	01/09/2001
007	125.0000	02/06/2001
008	125.0000	03/13/2001
009	125.0000	04/10/2001
010	125.0000	05/08/2001
011	125.0000	06/12/2001

Total: [redacted]

APPENDIX 3 (viii)

RED CELL SCHEDULE 3/13/00

DUE	W.O.#	PART#	DESC.	LEFT	PART#	DESC	QTY	COMMENTS
11-Feb	52871	64640F		1/6	444900R	PC BD	1	
7-Mar	55618	37560F		5	NONE			
7-Mar	55301	56780F		4	NONE			
8-Mar	55302	56820F		7	BUYERS SEE ATTACHED SHORT SHEETS			
9-Mar	55303	24380F		9	BUYERS SEE ATTACHED SHORT SHEETS			
10-Mar	55619	31220F		6	BUYERS SEE ATTACHED SHORT SHEETS			
13-Mar	55619	24375F		2	NONE			
13-Mar	55304	31210F		8	BUYERS SEE ATTACHED SHORT SHEETS			
14-Mar	55308	31280F		3	BUYERS SEE ATTACHED SHORT SHEETS			
15-Mar	54459	56880F		3	BUYERS SEE ATTACHED SHORT SHEETS			
16-Mar	55622	31220F		6	BUYERS SEE ATTACHED SHORT SHEETS			
17-Mar	55310	37560F		8	NONE			
20-Mar	55628	56770F		3	BUYERS SEE ATTACHED SHORT SHEETS			
21-Mar	55791	31240F		3	BUYERS SEE ATTACHED SHORT SHEETS			
21-Mar	56015	56810F		2	BUYERS SEE ATTACHED SHORT SHEETS			
23-Mar	55305	64580F		7	BUYERS SEE ATTACHED SHORT SHEETS			
24-Mar	55620	64560F		4	BUYERS SEE ATTACHED SHORT SHEETS			
24-Mar	55624	64540F		3	BUYERS SEE ATTACHED SHORT SHEETS			
27-Mar	55920	64680F		6	BUYERS SEE ATTACHED SHORT SHEETS			
28-Mar	55306	64680F		1				
28-Mar	55309	64640F		1				
29-Mar	56296	37560F		8				
29-Mar	55821	31230F		3				
30-Mar	56016	24370F		8				
31-Mar	55623	24380F		8				
31-Mar	55627	31210F		2				
31-Mar	55625	56780F		6				

3/31 END OF MONTH

Page 1

APPENDIX 3 (ix)

[illegible] X

MRP Exception R [illegible]
By Analyst: [illegible]

Cycle: W

03/10/00 07:40 PAGE 44
As Of: 03/13/00

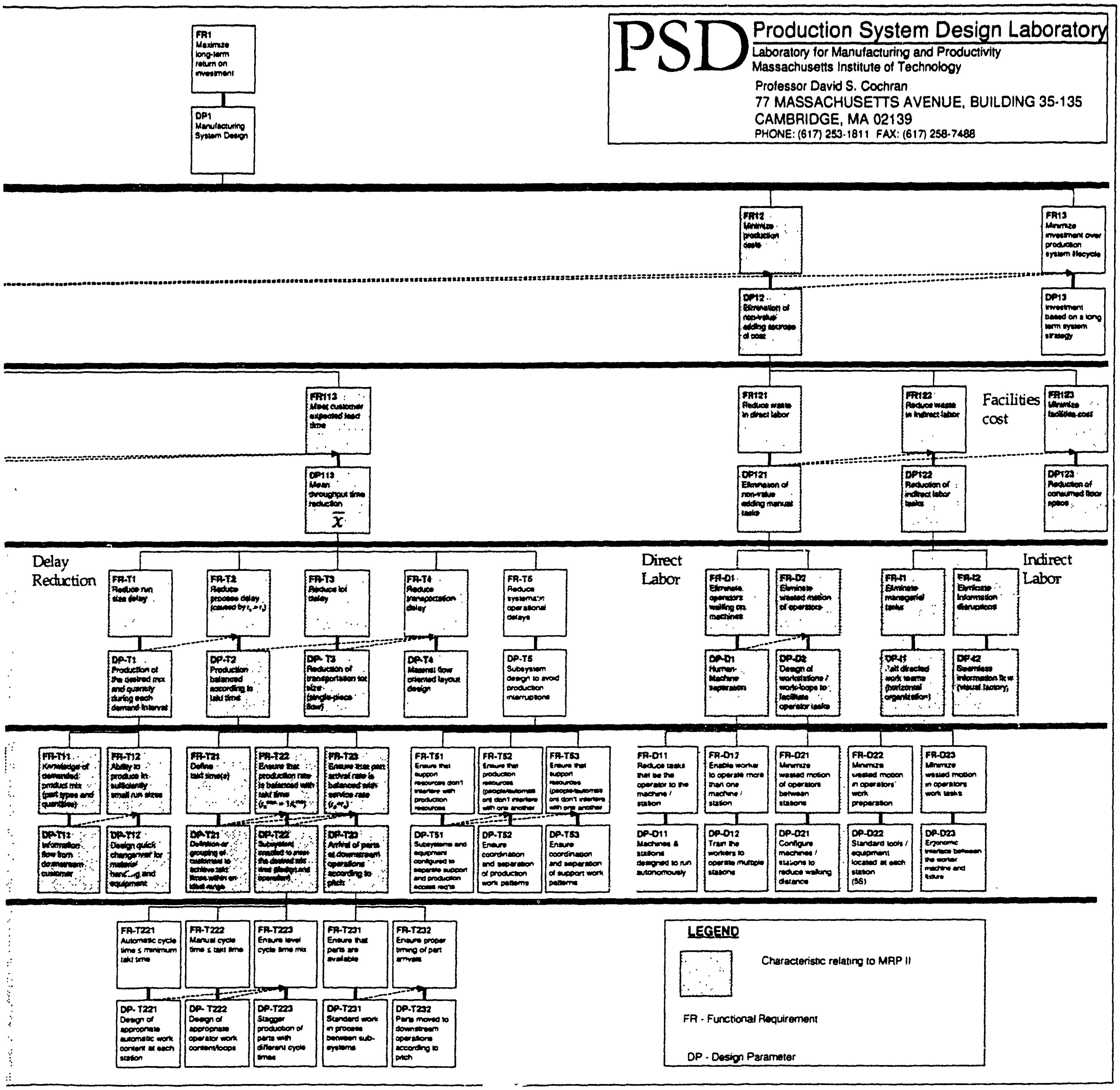
Item	Revision	Exception	Order Number	Order Qty	UM	Except Date	Plan Date	Resch to Date
002090R								
		Reschedule In	35642	100.0000	EA	06/20/00		05/10/00
003150R								
		Reschedule Out	34893	240.0000	EA	04/26/00		06/28/00
		Reschedule In	34893	1600.0000	EA	08/04/00		07/26/00
003258R								
		Reschedule In	35106	1500.0000	EA	03/23/00		03/17/00
003500R								
		Reschedule Out	35735	500.0000	EA	06/01/00		08/29/00
003740R								
		Reschedule Out	33419	174.0000	EA	04/05/00		05/16/00
005130R								
		Reschedule In	35226	250.0000	EA	03/08/00		02/16/00
005700R								
		Reschedule In	33932	1800.0000	EA	03/14/00		03/03/00
		Reschedule Out	33932	1800.0000	EA	05/16/00		06/27/00
005710R								
		Reschedule Out	34892	1200.0000	EA	05/02/00		06/07/00
005750R								
		Reschedule In	[illegible]	50.0000	EA	03/14/00		03/03/00
		Reschedule Out	[illegible]	250.0000	EA	04/10/00		07/11/00
005810R								
		Reschedule In	[illegible]	125.0000	EA	03/08/00		02/25/00
005820R								
		Reschedule In	35645	125.0000	EA	03/08/00		02/25/00
006760R								
		Reschedule Out	35412	1500.0000	EA	05/05/00		06/07/00

APPENDIX 3 (x)

COMPANY X

03/13/00 1Open WO with Sho

Due Date	Work Order	WO Itm	Desc	Component	Analyst	Desc	Short
03/08/00	55302	056820F		65452BF	DH	BEZEL	4.00
03/09/00	55303	024380P		43891AF	DHP	D'ASSY COVER REFRIG.	6.00
				444700R	AFPC	ASSY PC BD MP#R UPGRADE	9.00



PSD
Production System Design Laboratory
Laboratory for Manufacturing and Productivity
Massachusetts Institute of Technology
Professor David S. Cochran
77 MASSACHUSETTS AVENUE, BUILDING 35-135
CAMBRIDGE, MA 02139
PHONE: (617) 253-1811 FAX: (617) 258-7488
FR1 Maximize long-term return on investment
DP1 Manufacturing System Design
FR12 Minimize production costs
DP12 Elimination of non-value adding sources of cost
FR13 Minimize investment over production system lifecycle
DP13 Investment based on a long term system strategy
FR113 Meet customer expected lead time
DP113 Mean throughput time reduction
FR121 Reduce waste in direct labor
DP121 Elimination of non-value adding manual tasks
FR122 Reduce waste in indirect labor
DP122 Reduction of indirect labor tasks
Facilities cost
FR123 Minimize facilities cost
DP123 Reduction of consumed floor space
Delay Reduction
FR-T1 Reduce run size delay
DP-T1 Production of the desired mix and quantity during each demand interval
FR-T2 Reduce process delay (caused by ra > rs)
DP-T2 Production balanced according to takt time
FR-T3 Reduce lot delay
DP-T3 Reduction of transportation lot size (single-piece flow)
FR-T4 Reduce transportation delay
DP-T4 Material flow oriented layout design
FR-T5 Reduce systematic operational delays
DP-T5 Subsystem design to avoid production interruptions
Direct Labor
FR-D1 Eliminate operators waiting on machines
DP-D1 Human-Machine separation
FR-D2 Eliminate wasted motion of operators
DP-D2 Design of workstations / work-loops to facilitate operator tasks
FR-I1 Eliminate managerial tasks
DP-I1 Self directed work teams (horizontal organization)
FR-I2 Eliminate information disruptions
DP-I2 Seamless information flow (visual factory)
Indirect Labor
FR-T11 Knowledge of demanded product mix (part types and quantities)
DP-T11 Information flow from downstream customer
FR-T12 Ability to produce in sufficiently small run sizes
DP-T12 Design quick changeover for material handling and equipment
FR-T21 Define takt time(s)
DP-T21 Definition or grouping of customers to achieve takt times within an ideal range
FR-T22 Ensure that production rate is balanced with takt time
DP-T22 Subsystem enabled to meet the desired takt time (design and operation)
FR-T23 Ensure that part arrival rate is balanced with service rate
DP-T23 Arrival of parts at downstream operations according to pitch
FR-T51 Ensure that support resources don't interfere with production resources
DP-T51 Subsystems and equipment configured to separate support and production access req'ts
FR-T52 Ensure that production resources (people/automation) don't interfere with one another
DP-T52 Ensure coordination and separation of production work patterns
FR-T53 Ensure that support resources (people/automation) don't interfere with one another
DP-T53 Ensure coordination and separation of support work patterns
FR-D11 Reduce tasks that tie the operator to the machine / station
DP-D11 Machines & stations designed to run autonomously
FR-D12 Enable worker to operate more than one machine / station
DP-D12 Train the workers to operate multiple stations
FR-D21 Minimize wasted motion of operators between stations
DP-D21 Configure machines / stations to reduce walking distance
FR-D22 Minimize wasted motion in operators' work preparation
DP-D22 Standard tools / equipment located at each station (5S)
FR-D23 Minimize wasted motion in operators work tasks
DP-D23 Ergonomic interface between the worker, machine and fixture
FR-T221 Automatic cycle time ≤ minimum takt time
DP-T221 Design of appropriate automatic work content at each station
FR-T222 Manual cycle time ≤ takt time
DP-T222 Design of appropriate operator work content/loops
FR-T223 Ensure level cycle time mix
DP-T223 Stagger production of parts with different cycle times
FR-T231 Ensure that parts are available
DP-T231 Standard work in process between sub-systems
FR-T232 Ensure proper timing of part arrivals
DP-T232 Parts moved to downstream operations according to pitch
LEGEND
Characteristic relating to MRP II
FR - Functional Requirement
DP - Design Parameter

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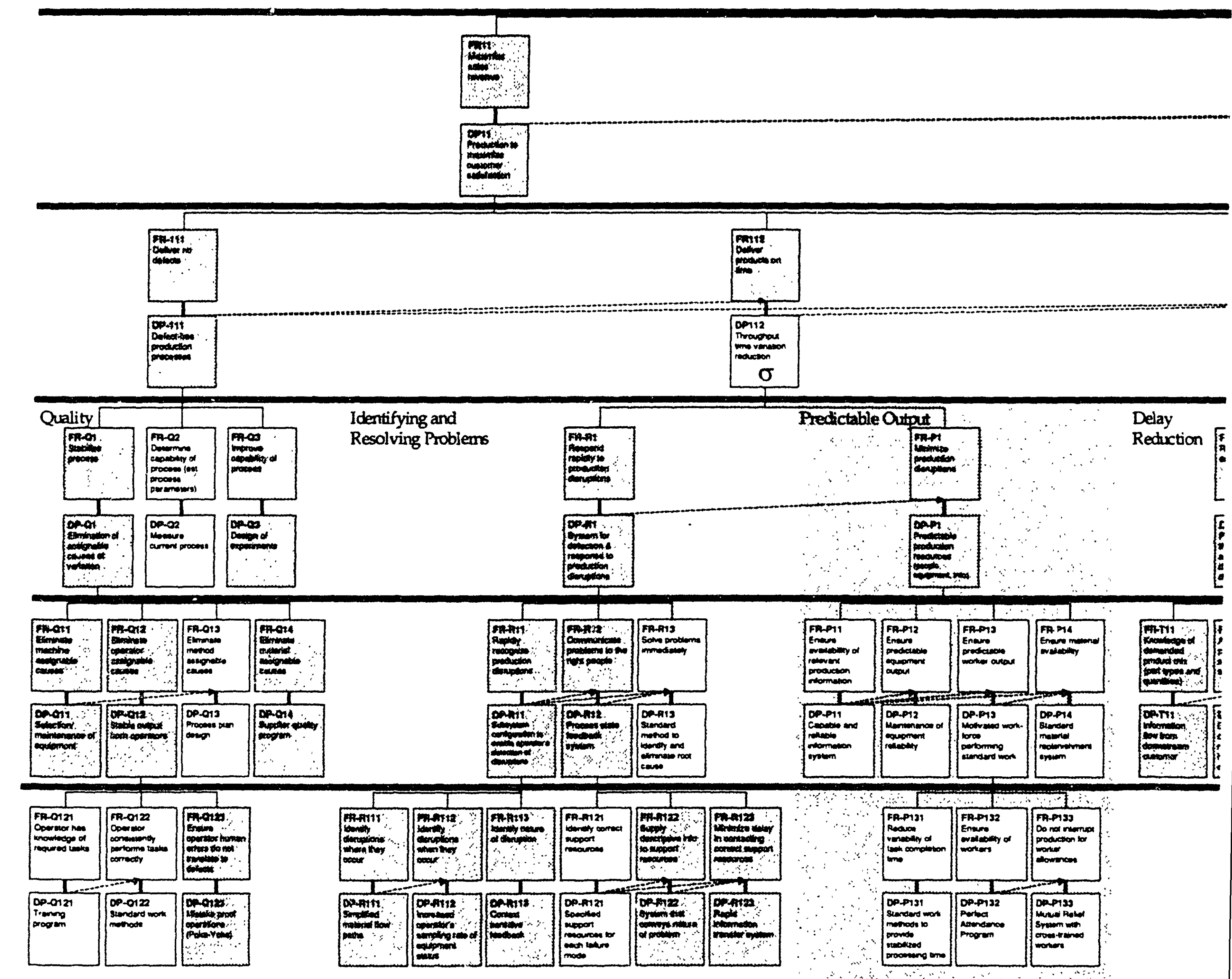

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