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**Setting Parameters in MRP for the Effective Management
of Bought-Out Inventory in a JIT Assembly Environment**

Sandeep Shah

Doctor of Philosophy

The University of Aston in Birmingham

January 1992

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Synopsis

In recent years, UK industry has seen an explosive growth in the number of 'Computer Aided Production Management' (CAPM) system installations. Of the many CAPM systems, materials requirement planning/manufacturing resource planning (MRP/MRP II) is the most widely implemented.

Despite the huge investments in MRP systems, over 80 percent are said to have failed to deliver the expected benefits. Many people now assume that Just-In-Time (JIT) is the best manufacturing technique. However, those who have implemented JIT have found that it also has many problems. The author argues that the success of a manufacturing company will not be due to a system which complies with a single technique; but due to the integration of many techniques and the ability to make them complement each other in a specific manufacturing environment.

This dissertation examines the potential for integrating MRP with JIT and Two-Bin systems to reduce operational costs involved in managing bought-out inventory. Within this framework it shows that controlling MRP is essential to facilitate the integrating process.

The behaviour of MRP systems is dependent on the complex interaction between the numerous control parameters used. Methodologies/models are developed to set these parameters. The models are based on the Pareto principle. The idea is to use business targets to set a coherent set of parameters, which not only enables those business targets to be realised, but also facilitates JIT implementation.

It illustrates this approach in the context of an actual manufacturing plant - IBM Havant. (IBM Havant is a high volume electronics assembly plant with the majority of the materials bought-out). The parameter setting models are applicable to control bought-out items in a wide range of industries and are not dependent on specific MRP software. The models have produced successful results in several companies and are now being developed as commercial products.

Key words: Inventory control, MRP, JIT, Two-Bin, Ordering policies, Rescheduling and Dampening policies, Safety Rules.

"To remain in business in the 1990s, manufacturing companies must continue to examine and seek to change their planning and control practices in order to improve their competitiveness" - BPICS Control June/July 1990

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Finally, I dedicate this dissertation to my wife, in recognition of her tremendous personal sacrifice, her encouragement, her patience, and above all her support.

Chapter 1

Introduction

1.1 CAPM

Computer Aided Production Management (CAPM) began in the early 1960s when large manufacturers and computer suppliers promoted concepts and developed software for production planning and inventory control. CAPM systems cover:

- a. Material Requirements Planning (MRP)
- b. Manufacturing Resource Planning (MRPII)
- c. Sales Order Processing
- d. Scheduling Systems
- e. Optimised Production Technology (OPT)

They are also complementary philosophies such as:

- a. Just-In-Time (JIT)
- b. Total Quality Management (TQM)

Of all the modern CAPM systems, Manufacturing Resource Planning offers the most complete suite of tools. It is the most widely implemented and part of its database is often used for other systems such as OPT.

Despite the huge investments in MRP systems, few users have claimed to enjoy great success. Recent research by individuals such as Whiteside and Arbose (1984), Aggarwal (1985) and Fintech (1989), amongst others, have estimated that over 80 percent of the MRP systems could be classified as failures. But users are forced in an upward development spiral of even more sophisticated systems to support the highly complex nature of today's manufacturing environment and competitive pressures from the Japanese.

On the other hand, the Japanese are dominating the manufacturing arena with their simple JIT philosophy. Many leading edge western companies are recognising the advantages of JIT and are embracing it, but without overwhelming success. On the

whole, most western companies still embrace systems which do not work for them - Dear (1988).

1.2 Research Area

Simple, manually controlled reorder point (ROP) systems such as 'Two-Bin' were the dominant doctrine prior to MRP. However, as the cost of MRP systems declined, these traditional approaches were abandoned in favour of MRP. MRP systems have become a dominant method in production and inventory management over the last two decades in the US, and more recently in the UK.

Well designed and successfully implemented MRP systems can help manufacturing plants reduce inventory, improve customer service and increase operating efficiency. However, as noted earlier, MRP has a significant history of implementation problems. Many now believe that JIT is the best manufacturing "technique", while others believe in MRP. However, the author argues that the success of a manufacturing company will be due to the integration of many techniques and the ability to make them complement each other in a specific manufacturing environment.

This dissertation examines the potential for integrating JIT/Kanban, MRP, and the more traditional Two-Bin system to control bought-out inventory in a repetitive assembly environment. This will be illustrated in the context of an actual manufacturing plant - IBM Havant.

It will be demonstrated that the design and integration of JIT/Kanban, MRP, and the traditional ROP approaches play an important role in matching the performance of the total manufacturing system to the business objectives. Integrating JIT/Kanban, MRP and ROP poses a number of interesting challenges because of their conflicting characteristics (a simple example based on historical evidence of the use of systems in practice is illustrated in Table 1.1). Clearly, indiscriminate integration of these systems will lead to a mismatch of performances and ultimately, failure.

Table 1.1 - Characteristics of ROP, MRP and JIT/Kanban

<u>ROP</u>	<u>MRP</u>	<u>JIT/Kanban</u>
o EOQ lot sizes	o "Optimised" lot sizes	o Smaller lot sizes
o Control disciplines assumed	o Control disciplines assumed	o Ensures control
o Designed for independent demand	o Designed for batch environment	o Designed for repetitive environment

Many of the modules in MRP are required by the other two systems. Therefore one of the key requirements for a successful marriage is the ability to control the performance of MRP. MRP performance is affected by the complex interaction between the numerous operational policies, rules and parameters such as ordering, rescheduling, and safety. Despite this importance, very little guidance is available today for selecting and setting the appropriate policies, rules, and parameters. What little guidance is available, concentrates on the part number level (micro level) performance. But the most important concern for production managers is the performance of the whole system (macro performance) and how that system can be controlled to match changing business conditions. That is, the design and operation of the manufacturing control systems should be viewed in global terms (macro level) as well as at the part number level (micro level).

This dissertation will develop methodologies to set appropriate parameters to control the macro performance and evaluate their impact on the business. The methodologies developed will also facilitate the implementation of JIT/Kanban.

1.3 Industrial Experimental Facility - IBM Havant

IBM Havant has an inventory turnover in excess of £350 million per year. It is one of 14 IBM manufacturing plants within Europe and its main product groups are: ‘

- a. small and intermediate disk drives,
- b. telecommunication units,
- c. and to a lesser extent, cash dispensers.

Havant is predominantly a batch assembly plant with the production system subjected to varying levels of product complexity and demand uncertainty. The majority of the items are bought-out either from vendors or sister plants. (Details of IBM Havant are in Appendix A).

The 'high-tech' electronic environment (as every other environment) is becoming highly competitive. Havant sees 'Continuous Flow Manufacturing' (CFM), (IBM's JIT system), as the key to achieving an efficient manufacturing operation to remain competitive. In 1984, CFM was introduced to Havant with the aim of eliminating waste and simplifying processes - both manufacturing and production control. This laid the foundation for integrating CFM and their multi-plant MRP system called EPRG.

Havant understood the need to integrate these two systems and develop a coherent control policy for the operation of the whole system. The potential for conflict between the two systems was recognised. It was also clear that understanding the interaction between different parameters and the ability to control them, and react quickly to changes, would be the key to achieving the apparently conflicting objectives of:

- a. lower inventory
- b. minimum production costs
- c. higher service level
- d. reduced workload i.e. ordering/receiving workload (a JIT environment compounds the problem, since smaller more frequent deliveries increase the workload)

This finding concurred with the report commissioned in 1985 by the ACME (Application of Computers to Manufacturing Engineering) Directorate of the Science and Engineering Research Council (SERC) and produced by Waterlow and Monniot (1986).

To address the problems, IBM Havant and SERC jointly funded this research project to investigate and understand the complex inter-relationship between policies, rules,

parameters, and management controls. With this backdrop, the objective of the research was to design appropriate methodologies which will help production managers to make informed decisions to gain maximum benefit from their systems.

1.4 Map of the Dissertation

The dissertation consists of 4 logical sections as depicted in Figure 1.1. The first section compares and contrasts the three systems - ROP, MRP, and JIT and highlights the issues and problems surrounding MRP within an increasingly JIT environment. More specifically, chapter 2 reviews the development of the three systems and compares their relative merits. In chapter 3 the general issues in MRP under the modern environment are reviewed, followed by an analysis of the factors affecting MRP performance in chapter 4.

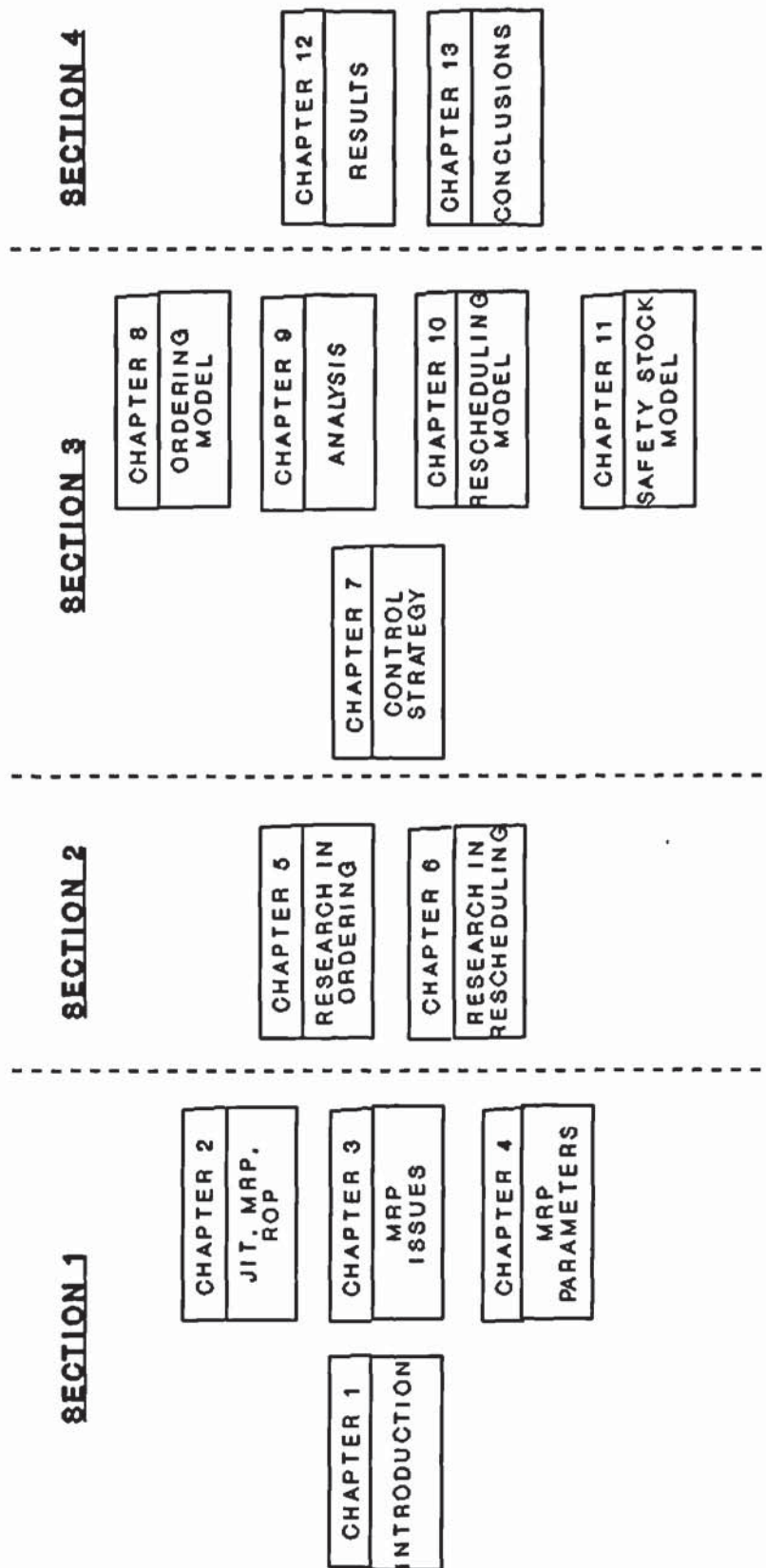
Of the many issues in MRP, ordering and rescheduling of orders are the most critical, and key to controlling and stabilizing MRP. These issues affect inventory performance and the whole cost of manufacturing operations. Because of their importance the second section reviews the strengths and limitations of existing research in these two areas separately. Chapter 5 reviews research in ordering policies and chapter 6 reviews research in rescheduling policies.

Having laid the general background, the third section goes on to discuss the ordering, rescheduling and safety stock strategy for integrating and controlling MRP to reduce the total cost of production planning and control. Chapter 7 discusses the general strategy and the concepts involved while the detailed methods are developed in chapters 8 through to 11.

Finally, the fourth section presents the actual results and concludes the dissertation. Chapter 12 presents the actual performance of IBM's system over a period of two years after the methods were implemented and compares this performance with the expected one. Finally, chapter 13 concludes the research and suggests issues for future system designs and research.

FIGURE 1-1

LOGICAL MAP OF THE DISSERTATION



Chapter 2

Review of Inventory Control Systems

2.1 Introduction

The assumption is often made that integrating ROP, MRP and JIT/Kanban is vital to the success of a manufacturing company. Before a strategy for integrating such systems is developed, it is necessary to understand the difference between the various inventory control systems in operation today. These are reviewed in this chapter.

2.2 Reorder Point Systems

Broadly speaking, there are two major approaches to materials control: Material Requirement Planning (MRP) and Reorder Point (ROP). A reorder point (also called order point) is a simple concept: when stock, including existing orders on suppliers, reaches a predetermined reorder point, a new order is placed on the supplier (or on production). Having decided to place an order (when the reorder point is reached), the next decision is to determine the order size (how much to order). The order size is invariably calculated using the 'Economic Order Quantity' (EOQ) formula. In practice, the EOQ formula has many limitations which will be discussed in chapter 5.

2.2.1 Two-Bin (Max/Min) System

Of the many approaches in ROP, Two-Bin (often called Max/Min) systems are the simplest and were widely used before MRP. A Two-Bin system is a simple visual reorder point technique: when the supply of an item is down to where you must dip into the second bin, you reorder. Although it is simple, the disadvantage of using this technique is that it results in high inventory. Items are ordered because of the rule instead of need. The details of this technique can be found in Silver and Peterson (1985).

2.2.2 Pareto (ABC) Principle

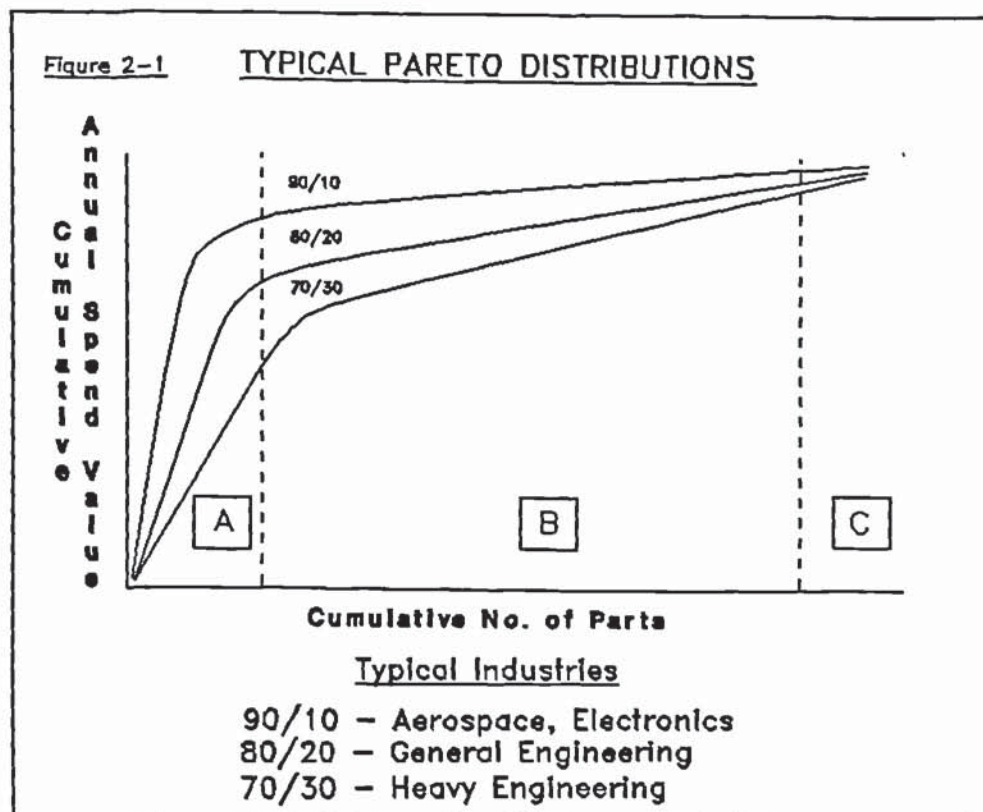
A ROP system can be significantly improved upon by adopting decision rules that do not treat every item equally - an expensive item deserves a higher degree of control

than a less expensive one. This is the Pareto (also known as 'ABC') principle where parts are classified and controlled according to their annual usage value (AUV). (AUV = item's unit cost * average annual demand).

The Pareto principle is simple and is also widely used in industry. In a comprehensive survey by Davies (1975) he found that the Pareto approach was used by over 60 percent of the users to control inventory prior to MRP.

2.2.2.1 Pareto Shapes and Boundaries

A general observation in industry is that somewhere around 20 percent of all the items account for approximately 80 percent of the total annual usage value (AUV) of the plant. Figure 2.1 shows typical Pareto distributions commonly found in different industries - Aggarwal (1983).



The Pareto principle is often called the 'ABC' principle because it is common to use only 3 classes or control groups: class 'A' contains the top 5 to 10 percent of the items and accounts for somewhere in the neighbourhood of 50 percent of the total annual usage value. Class A items receive the most personalised managerial attention and are subjected to the highest degree of control because they can potentially yield higher inventory savings.

Class 'B' items are of secondary importance in relation to class A. These items receive a moderate amount of attention and are less tightly controlled than class A. The largest number of items may fall into this category: usually more than 50 percent, and they account for most of the remaining total annual usage value.

Class C items are the remaining items that make up only a minor part of the total investment. For these items the decision rules are kept as simple as possible.

2.2.2.2 Ordering and Reviewing Decision Rules

The ordering and reviewing decision rule generally used with the ABC rule is the 'weeks' or 'months' worth of supply. (This will be discussed in detail in chapter 5). For instance, the 'A' items could be reviewed weekly and the lot size ordered is equivalent to a weeks demand, while the 'B's could be reviewed and ordered monthly and the 'C's, say quarterly.

In reorder point systems, the demand of the individual items is unknown. Therefore the ordering decisions are based on a forecast of demands. To protect against shortages occurring in between reviews, blanket protection based on the Pareto principle, is often used: The 'C' items may be buffered heavily, while the 'B's may receive a moderate level of protection and the 'A's a marginal amount.

Blanket buffering of this sort is both ineffective and expensive. It is obvious that not all of the items (within a given group) will need the same level of buffering - some will be more prone to shortage than others. So it sounds logical to transfer some investment from the low risk parts to the high risk items - hence achieving a higher

service level for the same total inventory investment. This idea seems simple, but currently there are no simple methods to rebalance the protection in practice. These limitations are discussed fully in chapter 5 and in chapter 11 a methodology is described to rebalance the protection effectively.

2.2.2.3 Appraisal of the Pareto Principle

The advantage of the Pareto (ABC) technique is that managerial attention and effort is focused on the "significant few" (the A items) which have the highest potential saving. At the other extreme, less time is spent on the "trivial many" (the B and C items). This is an important consideration since resources (management time) are limited. Unfortunately, very few specific guidelines have been reported concerning how to use this analysis to improve inventory control. Research by Flores and Whybark (1987) noted that in industry it is all too common to find general statements like:

".... manage the A items more closely, spend less time on the C items...or order the A items more frequently".

Such statements only serve to explain the general principle but do little to actually define exactly which items should be controlled tightly or how much time should be spent on them etc. Although the Pareto principle is simple, there are many operational problems in operating this system, for instance:

- a. How many groups or categories should be used?
- b. Where should the class boundaries be?
- c. What should the ordering frequency be for each group?
- d. How much protection should be used in each class initially?

Generally, only 3 Pareto classes are used and their boundaries are arbitrarily chosen in industry. However, it will be shown in chapter 8 that the number of groups and the choice of boundaries make a significant impact on the levels of inventory and order workload and as such these decisions should be carefully considered. Also the ordering frequencies and protections are arbitrarily chosen without understanding their impact on the overall system (macro level) performance. To address all these problems a methodology is developed in chapter 7 which will aid a busy practitioner

to determine the appropriate boundaries, order cycles, and protection to achieve a given balance between inventory and workload.

2.3 History of MRP

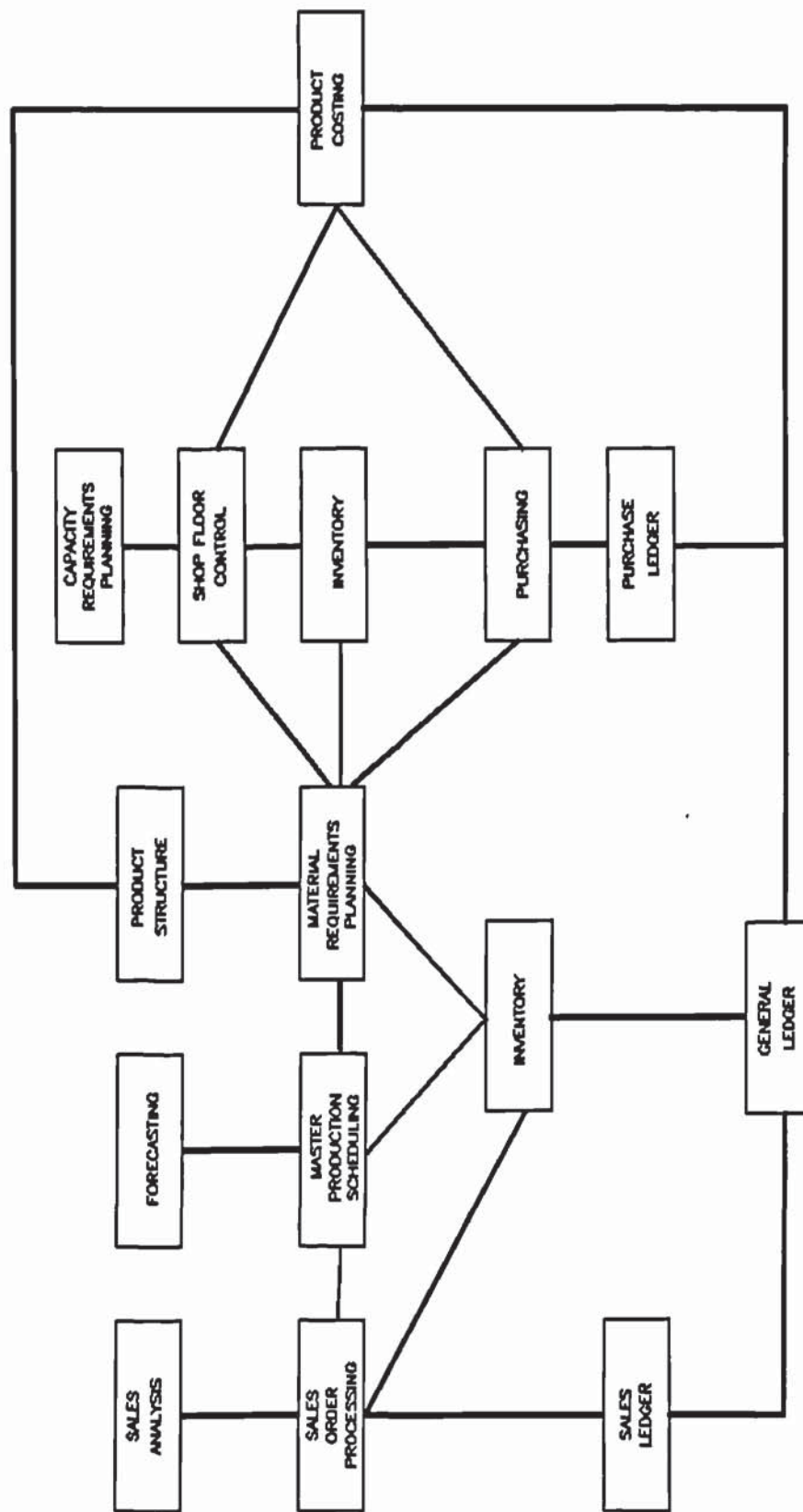
Production and inventory management has evolved hand in hand with the technology it utilises. In its earlier days scientific inventory management (reorder or order point techniques) was the prevalent doctrine. These techniques were simple, requiring minimal calculations to define the order points and order sizes. As discussed above, the order points and order sizes were determined rather informally using rough rule-of-thumb approaches.

The introduction of computers into manufacturing during the early 1960s gave the profession the opportunity to crunch massive amounts of data, hence the development of Material Requirement Planning (MRP) and the birth of so-called 'formal systems'. MRP is known as a 'formal system' because lot-sizes and order points are determined precisely using formal rules such as lead time off-sets, and ordering rules etc., discussed later. Early users of MRP in the USA were companies such as Black & Decker, JI Case, General Railway Signal, Jones & Lamson, Twin Disk, and others.

Later on, manufacturing 'gurus' such as Orlicky, Plossl and Wight, in the US, developed MRP systems to include the Master Production Schedule (MPS) function to drive MRP. The MPS process was to plan end items (called independent demand) or key option level components. Also, MRP systems were expanded to include capacity or resource planning and shop floor management systems. The enhanced systems were closed loop systems intended to control the total manufacturing process from initial planning to latest shop floor priority. (The term 'closed loop' refers to the fact that changes are fed back into the system to ensure that the plan is accurate). The closed loop MRP system, shown in Figure 2.2, was renamed MRPII (Manufacturing Resource Planning) to differentiate it from the simple MRP whose primary aim is to determine:

AN INTEGRATED CLOSED LOOP MRP II SYSTEM

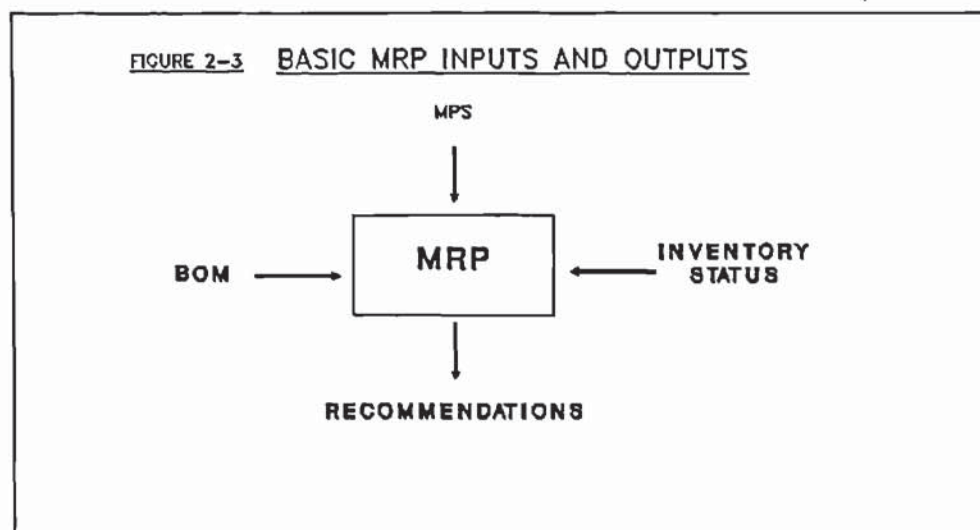
Figure 2-2



- a. what to order
- b. when to order
- c. how much to order

MRPII systems of the 1980s have now been refined to support many new characteristics. These include multi-plant systems, single and multi-level pegging, 'as-planned' and 'as-built' configuration control, product control on a project-by-project basis, and repetitive manufacturing control where materials are controlled by schedules instead of job lots. However, the original thrust of MRP has continued to remain the planning of materials, and launching of shop and purchase orders.

In the remainder of this dissertation the term MRP will be used to mean both Material Requirement Planning and Manufacturing Resource Planning since the only concern here is with the ordering process within the systems. Figure 2.3 shows the fundamental MRP inputs and outputs.



2.3.1 MRP Processing Logic

MRP is principally a "push" system, in the sense that a demand forecast is generated at the outset and a manufacturing plan is developed to meet those demands. The

plan then drives the manufacturing through the issue of shop and purchase orders. MRP is essentially a computerised database of parts, components, assemblies, finished goods, work in progress (WIP), and requirements. Lead times and relationships between parts are also held. The computer then calculates the best way to meet the Master Production Schedule (MPS). (A MPS is based on forecasts, customer orders, service demands and so on).

MRP plans material at all levels of a product by using bills of materials to create an 'explosion' process. This is shown in Figure 2.4. The simple MRP processing logic works as follows: Requirements are calculated in terms of quantity and time. These requirements are then 'exploded' in the BOM files which break down a product into its constituent parts. Net requirements are then calculated by deducting available inventory from gross requirements. Finally a schedule is calculated based on user defined parameters such as lot sizes and lead time offsets. The system then suggests shop and purchase orders.

2.3.2 Assumptions in MRP

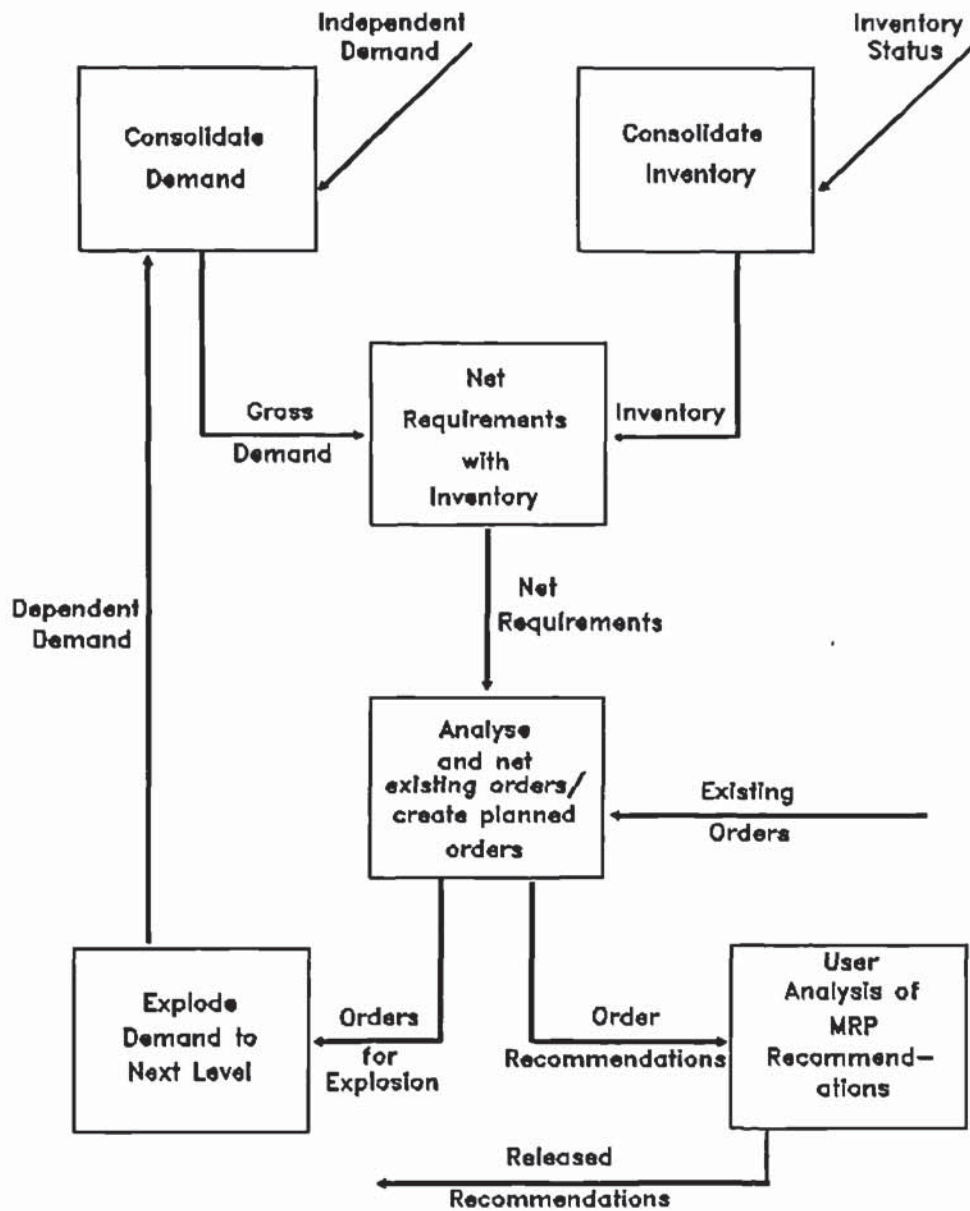
MRP is based on the following three assumptions for it to derive the orders:

1. The master production schedule is realistic and stable. Unrealistic and unstable schedules will lead to a mismatch between demand and production.
2. The lead time for each part number is usually fixed and independent of the lot size and any external influences such as shop load, production route etc...
3. The manufacturing capacity is infinite during the order generation process. Consequently, it ignores the total workload on individual work centres i.e. it assumes that what is scheduled will be produced on time.

In practice, both the MPS and lead times contain an element of uncertainty. Consequently, the orders generated by MRP will also be subject to uncertainty. This mismatch between planned demands and actual customer orders is the cause of frequent order reschedules or MRP 'nervousness'. Ho (1989) noted that nervousness is the key cause of MRP failures in industry. Unfortunately, traditional research in MRP has failed to develop simple and practical rules to reduce nervousness. The

FIGURE 2-4

SIMPLE MRP PROCESSING LOGIC



limitations of traditional research to reduce nervousness will be discussed more fully in chapter 6.

2.4 Origins of JIT

In the 1950s, postwar Japan began to examine their industrial system to develop a world class manufacturing base. Initially, they developed a strategy to take advantage of the large labour force and the lack of serious competition from the Pacific Basin area. They targeted their efforts at products which possessed the following characteristics:

- a. Products entering a mature stage of their life cycle
- b. Standardised products which could be produced in large volumes
- c. Price-sensitive products which could be made cheaply due to economy of scale
- d. Products utilising well-established production technology
- e. Products that are only assembled from purchased components

Consumer products such as cars, cameras, and watches fitted the bill. After careful analysis of the products, the Japanese invested heavily in modern production facilities for selected product lines. They combined these factors to produce relatively low cost, yet high quality goods which were successfully marketed worldwide.

This strategy was successful for a time, but to meet the growing international price competition, Japanese management had to look beyond their low cost labour element to achieve a continued cost reduction. Material procurement and inventory management then became a focal point for major cost reduction efforts. Thus the JIT concept was born. Origins of JIT can be traced to the Toyota car company. In the early 1960s Toyota was working on the philosophy of extending the assembly line back through all the feeder operations (including supplier logistics). Their goal was to put raw materials in at one end, one piece at a time, and produce a car at the other end, one at a time.

Their approach was to integrate and simplify planning and manufacturing. As part of the simplification process, all forms of waste were either reduced to a minimum or eliminated completely. Waste is defined as:

"...anything other than the minimum amount of equipment, materials, parts, and workers (working time) which are absolutely essential to production." - Dr Cho of Toyota (1977)

As part of the simplification, they developed "KANBAN", a scheduling process that works on the principle that each feeder operation replaces what is consumed by the next succeeding operation.

2.4.1 Kanban

Kanban literally translated means visible record. More generally, Kanban is taken to mean card. In the simple Kanban system as described by Schonberger (1982) (known as the single-card Kanban and schedule system), an empty container automatically becomes an authorization to refill the container with a predetermined quantity of the same item. While it is simple to operate and control, it results in unnecessary inventory because items are replenished due to the rule rather than the need. The simple Kanban system is essentially a Two-Bin system which was traditionally used in the US (described earlier in section 2.2) and suffers from the same problems. Kanban's uniqueness lies in the fact that it is part of a coordinated JIT system. It has the following characteristics:

- a. Standard containers are used.
- b. The quantity per container is exact, so that inventory is easy to count and control.
- c. The number of full containers at the point of use is only one or two.
- d. At the producing end, the containers are filled in small lot sizes. (This requires prior action to cut set-up times and thereby make small lot sizes economical).
- e. To support production with minimum inventory, 100 percent quality is essential.

To overcome the problems of unnecessary inventory, Toyota developed the two-card system (known as the dual-Kanban system) where items are only replenished when it receives a "positive" pull signal. In simplistic terms, when a container is empty it must only be refilled if it receives an authority to do so from the consuming operation. Receipt of the second card acts as the authority. The two-card Kanban synchronises the production/supply of each item to match the fluctuating output rate of the succeeding production stage.

There are numerous fine points to the Toyota dual-card Kanban system. A full discussion can be found in publications by Hall (1981), Monden (1981), and Sugimori et al. (1977). Despite the advantages of the Toyota dual-card Kanban system, only a small number of Japanese companies have implemented the complete Toyota system; most just have a single-card Kanban system - Schonberger (1982).

2.4.2 Principles and Techniques of JIT

As is implied in the last section, JIT is a philosophy which is based on the following main principles:

- a. Process Simplification
- b. Elimination of Waste
- c. Total Quality

The premise of using the JIT concept is to reduce product cost through reduction in cycle times (lead times), inventory levels, and waste. These objectives are met by employing, but not limited to the following techniques:

- a. Reducing cycle times to quickly react to customer demand.
- b. Eliminating set-up time through better product design and use of flexible manufacturing tools.
- c. Eliminating all aspects of waste.
- d. Improving product quality through worker involvement.

2.4.3 Criticism of JIT/Kanban

The benefits of JIT/Kanban are unquestionable (Schonberger - 1982) and many companies would like to operate a simple pull system. However, implementing JIT/Kanban right across the whole range of parts is infeasible in practice. A typical manufacturing plant has several thousand components. JIT/Kanban manufacturing is not economical for the very low value items because the inherent cost of managing the production process, in terms of the set-up costs etc., will be higher than the value of the component. Similarly, JIT/Kanban deliveries are also not possible right across the spectrum because of the difficulties in negotiating purchasing contracts for a very large number of items and suppliers and again, the cost of managing the 'material logistics chain' will be much higher compared to the cost of the very low value items.

These are some of the lessons learnt from the IBM experience. In practice companies such as IBM who are implementing JIT/Kanban have found that it is only economical to implement JIT/Kanban to manage the very high usage value, repetitive items.

Secondly, according to IBM's JIT world experts, JIT/Kanban requires a stable demand over an extended period, almost certainly months to be successful. In many cases demand stability (stable master production schedules) is achieved by certain restrictive practices. For instance, this research found that Honda imposes a frozen zone (frozen zone restricts demand changes) of at least six months on certain key assemblies to Rover of UK - in certain cases the items frozen are as trivial as left hand or right hand engine mount clamps. (The clamps are of low value and can easily be switched).

Thirdly, as Vickerby (1989) found, many large manufacturers simply pass the burden of carrying inventory to their suppliers. In many cases, JIT/Kanban material supplies are being achieved by expanding the pipeline supplies - be it in the transport logistics chain, or off-shore stores etc. Therefore in many cases inventory reduction may simply be an illusion. It only serves to distort the true production costs and does little to reduce the total production costs. Unfortunately, in industry there is a general lack of awareness between inventory reduction and cost reduction. Management assume that reducing inventory means reducing costs. The author's observations indicate that when production controllers are given the objective to reduce inventory they simply increase the delivery frequencies. Without genuine process simplification and waste elimination, frequent deliveries only lead to an increase in the total 'acquisition costs'. This issue will be discussed in chapter 7.

This suggests that there is a conflict between JIT/Kanban philosophy and practice. JIT/Kanban dictates that set-up times should be made negligible. Therefore, any item can be produced as and when required at minimum cost. But to minimise production costs it is necessary to preplan production which ultimately means limiting customer changes. In today's manufacturing environment, facilitating customer changes, or put another way, being responsive to customers is a key objective, i.e. supply the

customer with what he wants, when he wants it - not when you can fit him in!

2.5 Summary - ROP,MRP,JIT/Kanban

The reorder point (ROP) system is based on a simple principle: when stocks get low, order more. Of the many ROP systems, Two-Bin systems were widely used before MRP because they were very simple systems to understand and operate. In practice operating the Two-Bin system has resulted in high levels of inventory (inventory is ordered because of the rule rather than the need). The Two-Bin systems were improved upon by using the simple Pareto (ABC) principle. However, despite its simplicity the ABC system has suffered from a lack of general guidelines. Although these traditional systems have been abandoned in favour of MRP, it will be shown that both of these systems have a place in modern manufacturing control systems when used as part of an integrated and coordinated system.

Material Requirements Planning (MRP) provides a better way and has come to replace all but a few of the ROP systems. MRP is essentially a 'push' system. It transforms a master schedule of end products into parts requirements. Both MRP and ROP share a common drawback: they are 'lot' orientated. They lump demands into lots, rather than piece for piece as in JIT systems. Another crucial factor is that MRP calculates parts requirements by precisely associating them with the master schedule. But what is correct at the time of calculation is subject to error later because the master production schedule is almost always based on a forecast. Consequently a mismatch occurs between actual requirements and production. Frequent mismatches and adjustments lead to MRP nervousness, which is cited to be a key cause of ultimate MRP failure.

While the US was refining MRP, Japan instead was perfecting Just-In-Time. JIT is an approach wherein all forms of waste are systematically identified and eliminated to reduce costs. JIT/Kanban is a 'pull' system which is driven by the final assembly schedule. This schedule drives the whole production process. In its simplest form, JIT/Kanban is a shop floor control tool that allows the scheduling of inventory movement with the use of Kanbans. In practice, JIT manufacturing and purchasing

is only viable for the high usage value, repetitive items. It is not cost effective to manage the low usage value items in a JIT mode.

All three systems have certain limitations and strengths which are summarised in Table 2.1. A coherent methodology is developed in chapter 7 to integrate the 3 systems to minimise production costs while overcoming the limitations of the individual systems.

Table 2.1 Comparison of ROP, MRP, and JIT

	<u>ROP</u>	<u>MRP</u>	<u>JIT</u>
Development Era	1915	1960s	Mid 1960s to 1970s
Enabler	Mathematics	Computers	Common Sense (Highly visible & manual control systems)
Ethos	Scientific Theory	Control Systems	Philosophy
Early Gurus	F.W.Harris	Oliver Wight George Plossl Joseph Orlicky	Taichi Ohno Dr Cho Shigeo Shingo
Early Users	Ford	Black & Decker	Toyota
Typical Systems	Two-Bin (Max/Min) Pareto (ABC)	Many integrated modules eg. MPS, BOM, inventory status etc...	Kanban
Reasons for Development	Scientific approach to inventory planning and control	Eliminate the need to forecast dependent demand	Eliminate the need/cause of high WIP and inventory
Environment	Independent demand	Batch Assembly	Repetitive (Low variety, high volume)'
Lot Sizing	Large Lots (EOQ)	Large to medium lots (modified EOQ for MRP)	Small lots (Lot-For-Lot)
Inventory	High	Medium (Lower than ROP)	Low
General Assumptions	<ul style="list-style-type: none"> * Constant consumption (Historic consumption equals future usage) * Requirements of dependant items (children) independent of parent items * Safety stock to protect against demand and supply variability 	<ul style="list-style-type: none"> * Stable and deterministic MPS * Dependent requirements calculated from BOM explosion * Safety stock not required (but in practice is often left) * Fixed lead times * Infinite capacity 	<ul style="list-style-type: none"> * Stable and level MPS * Total quality * Short lead times * No supply variability

Chapter 3

Issues in MRP

3.1 Introduction

In chapter 2 it was noted that over the last 20 years, MRP has been the most widely implemented system. The reasons for installing a new system are usually clear and well known and frequently form the basis for cost justification. These include improved efficiency, lower inventory, better control etc., all seen as beneficial to the organisation. However, despite huge investments, few systems are reported to be successful. It is believed that the reasons for failure lie in the choice of effective operational policies and rules. These are often unclear. This chapter reviews the problems associated with choosing such policies and operating the system.

3.2 Business Environment and MRP

In the 1960s and early 1970s, the role and importance of production planning and inventory control was largely ignored or underestimated within the overall business strategy. Except perhaps for economy of scale, inventory was not considered a competitive weapon. Economy of scale was achieved through long production runs which minimised standard costs and maximised work centre utilization. Cheap finance was readily available to finance high levels of buffer inventory and WIP. The objective was to achieve sales targets through the market advantage offered by reduced unit costs. Production was largely planned against sales forecasts which in themselves were designed to support high work centre utilization. This in turn led to high levels of WIP.

MRP was in its embryonic stage then. The business thinking of the time became embedded in the MRP policy design. For instance, early pioneers of MRP such as Orlicky suggested that once the MPS (Master Production Schedule) was generated it could and should remain firm. Lot sizing and inventory rules were designed to order economic lot sizes to take advantage of the cheap finance and stable market conditions

etc. By today's standards, this epoch was characterised by:

- a. cheap finance
- b. long product life cycles
- c. low customer expectations
- d. little global competition

Today, intense international competition and business pressures mean customers now demand wide product choice, short lead times, and high quality. To maintain market share, manufacturers must now introduce more new products quickly i.e. the product life cycles are becoming shorter and shorter. Coupling this with high interest rates, it is forcing a change in business thinking. For example, leading edge companies have learnt from the Japanese that success hinges on amalgamating management practices with appropriate production systems discussed in chapter 2.

3.3 MRP Implementation Failures

There are many reasons for MRP implementation failures. There is a whole literature outlining the pitfalls e.g. Wallace (1985). There is general agreement that the universal causes of implementation failures are:

- a. Poor management support and commitment
- b. Poor data accuracy and structures
- c. Low level of training and education
- d. Poor project and implementation plans

The biggest cause of failure though, is when a company simply works to duplicate its existing methods and procedures on the new system. There is now a plethora of books, checklists, seminars, and professional help available to supposedly guarantee a successful implementation.

3.4 MRP Operational Failures

Solving the traditional implementation problems has not ensured operational success: MRP users still complain of poor due date performance, high inventory levels, and MRP systems with shop and purchase orders in a constant state of flux or reschedules. This frequent rescheduling of orders has resulted in a loss of faith in the

order schedules and has led users to often work outside the system - reverting to the familiar 'shortage driven' or 'hot list' systems, thus bringing the MRP system into further disrepute. Many eventually end up abandoning the MRP system altogether.

Operational failures are sometimes caused because the system is inappropriate; but more often the problem lies with the users - they do not know how to get the best out of what they have. Often they expect too much: they want the MRP system to 'control' their operation because they do not know how to do it themselves. At times these expectations display a complete lack of understanding of MRP. It is quite common for a company to adopt the "let's get the inventory recording right then think about control" approach. This approach draws an artificial distinction between recording and control. In effect it is putting off the problem of having to think through how to go about getting control.

The software suppliers for their part encourage high expectations. They go to considerable lengths to detail the benefits of tight inventory control; but gloss over how the user should use the system to achieve such gains. A MRP system cannot control inventory - it can only assist in that control.

So what are the real problems in MRP? Clearly, false expectations and a lack of understanding of the issues in MRP is a major cause of operational failure. However, the author believes that the key underlying inhibitors to a successful MRP operation are:

- a. poor choice of rules and parameters
- b. wrong assumptions
- c. lack of understanding of the policy interactions (complex inter-relationship between rules)

3.4.1 Poor Choice of Rules and Parameters

There are many reasons cited for MRP failures but none of the articles have highlighted the dependency on parameters for operational success. The actions suggested by MRP systems are dependent on the rules and parameters used, for

instance, ordering costs, rescheduling costs, lead time, safety stock, minimum and maximum order sizes etc.

MRP implementors and consultants place a relatively low level of importance on the choice of such rules and parameters; this is often due to poor understanding of the effects of such decisions - Clark (1988). It is usual to find that the pre-MRP parameters and values are implemented. The common view is that the system will automatically adjust for any deficiencies in choice. Poor choice of rules and parameters is compounded by the arbitrary business targets assigned by the users. Examples include due date performance, number of exception messages etc... (see Mather (1977)). Such arbitrary targets force the users into a spiral of "tweaking and tinkering" the system. Consequently, the user is never sure what the effect of different rules and parameters are, either individually or in combination. Tweaking the system in this fashion may result in violent oscillations in inventory levels and MRP recommendations.

If the parameters are not controlled, then the system will not be controlled. Literature research and discussions with many MRP users indicates that there are no formal policies/procedures to manage parameters at all - it is all up to whoever happens to be doing the ordering. The extent of the lack of management supervision on parameter setting is profound. Parameters are not kept up to date nor are they set in accord with clear, consistent management guidelines. Invariably, MRP users find themselves in situations such as these:

1. There are no clearly defined rules or guidelines for setting parameters. Indeed users do not even know which are the key parameters in order management.
2. The parameters are not up to date: many have not been changed or reviewed for months, or even years, in the majority of cases. Indeed, Wemmerlov (1979) noted that many of the parameters are inherited from the previous manual systems and are never changed.
3. Because the parameters are not up to date the recommendations of the system are not and cannot be followed.

Here lies the problem. While the parameters impinge on inventory and MRP control,

they attract the least time and attention. Users are aware that it is a problem; but they are unable to effectively come to grips with the difficulty by undertaking positive action. Instead, it is all too common to rationalise away the lack of action: we do not have the resources to devote to this exercise!

3.4.2 Wrong Assumptions

There is a consistent mismatch between assumptions made by MRP researchers and the dramatic changes in modern manufacturing and business philosophy discussed in section 3.2 earlier. Working towards JIT questions the wisdom of long production runs. JIT suggests that lots should be produced/ordered on as "needed" bases. Under the JIT philosophy, small batch sizes (or lot-less production) is the goal. But traditional research in ordering rules is focused on "optimal" or "economic" lot sizes and with the common assumption that the MPS (Master Production Schedule) should be held firm.

Furthermore, workers such as Goldratt (1981,1984), Fox (1983), St John (1984), and Jones (1987) amongst others have challenged the traditional cost measures such as inventory costs and ordering/set-up costs. They argue that whilst these costs are incurred they are however, unattainable in practice and in any case are fixed in the short term. Consequently, "leading edge" companies have developed marginal costing and cash flow measures for monitoring and controlling operational performance. Again this has not been reflected in policy design by traditional research.

3.4.3 Policy Interaction

There are a number of policies to be considered. For convenience, they are categorised into internal and external ones. External policies relate to the function of the MRP system in relationship to the overall manufacturing system and business strategy. Internal policies relate to the interaction of the policies within MRP (e.g. ordering rules, rescheduling rules etc.)

Up to now, external policy design has been little considered by previous research. The potential mismatch between the objectives of the company and the system is

generally not identified. Chapter 7 will show that the external policy design is the key to successfully meet the objective of the company.

Internal policies and rules in MRP form a complex chain stemming from customer orders right through to raw material supply ("Total Supply Chain"). Again, for convenience the policy interaction at the internal level is sub-divided into two levels: MPS and MRP. At the MPS level they include, but are not limited to:

- a. Degree of forecasting of customer orders
- b. Forecasting algorithms
- c. Level in the product structure at which MPS is applied
- d. MPS frozen zones

At the MRP level, policies and rules translate the net requirements into production and purchase order schedules. Commercial systems are offered with an array of rules and parameters. On close examination, all the MRP rules and parameters can be classified into 6 major categories. There are those that can be associated with:

- a. Ordering policies
- b. Rescheduling or Dampening policies
- c. Safety stock/safety lead time policies
- d. Order modifiers - e.g. packing factor, scrap factor etc...
- e. Lead time offsetting
- f. System operation - i.e. scheduled system run, type of production calendar, number of production days etc...

3.5 MRP Policy Design

The traditional approach to policy design has been to test the various internal policy alternatives in isolation. Examples include Silver and Meal (1973), Blackburn and Millen (1979), McClaren (1977), amongst many others. Interaction between policies at this level has been largely ignored. Clark (1988) suggests that the reasons behind this are twofold:

"Firstly, the implications and importance of policy interaction were not understood....The second reason behind the somewhat myopic view of policy interaction has been the lack of experimental facility with which to undertake such a study."

The interaction between policies, for instance variability in the MPS and ordering policies, have a profound effect on the system and cannot be ignored. The importance and impact of MPS variability on ordering policies was first highlighted in a valuable series of papers by De Bodt and Van Wassenhove (1980-1983). Their results raise serious doubts over the applicability of much of the previous research in MRP.

3.6 Summary

There is a host of professional help available to guarantee a successful MRP implementation. Nevertheless, no recipe has been developed guaranteeing operational success. Most companies are engulfed in a prolonged and agonizing operational problem; frequently resulting in confusion, general dissatisfaction, and a distressing variability in results. These operational problems are a result of poor choices of material control policies.

Under modern manufacturing pressures, a system is required with clearly defined control policies, rules and the like. These rules should be simple and reflect management's objectives for the business. For instance, if the business is experiencing a cash flow problem then this should be reflected in the inventory control system in a formal manner rather than just leaning on the stock controller. However, deriving even a simple set of rules is not easy - mainly because the interaction between different rules (and parameters) is not clearly understood. Currently, users set them by trial-and-error: If managers become involved, they tend to rely on the EOQ rules. Frequently, they expect that putting the inventory holding costs and the ordering costs into these equations will solve their problems. On the other hand, if managers do not become involved then the whole process becomes highly subjective and depends on whoever happens to be doing the job. Typically, the parameters are set using best guesses. The system is run for a period of time and if it does not perform as required, the rules and parameters are modified again. This cycle of 'tinker and test' is not adequate to achieve satisfactory results in a modern dynamic environment.

From the above discussions it is clear that the choice of policies, rules and parameters are fundamental to the successful performance of the whole manufacturing system. Therefore users need to know what these factors should look like and know in advance how they will perform.

Chapter 4

A Review of MRP Policies and Parameters

4.1 Introduction

MRP is a comprehensive decision support system implemented to manage the complexity of the manufacturing environment. In practice MRP has failed to achieve the inventory reductions possible, and as discussed in chapter 1, it is widely reported that over 80 percent of systems can be classified as failing to meet expectations.

While considerable focus has been attached to the cause of implementation failure, less successful research has been made into the operational design of MRP. The research that has been carried into operational policies and parameters may have been flawed. As discussed in the previous chapter this may be largely due to the poor understanding of the operational policies and parameters. This chapter reviews the major operational policies and parameters affecting MRP performance.

4.2 MRP Nervousness

Operationally, the so called "rescheduling" capability of an MRP system is its most important function. Rescheduling maintains valid production (shop) and purchasing schedules by realigning the due dates with the need dates. However, the frequent movement of orders is a major problem in MRP. This problem is generally referred to as 'system nervousness'.

MRP system nervousness is caused by the mismatch between planned demands and actual customer orders. This difference is amplified by the numerous but inappropriate choices of operational rules and parameters - (Peterson (1975), Steel (1975), Mather (1977)).

The operational variables can be categorised into:

- a. Lot sizing rules
- b. Rescheduling and dampening rules (including firm planned orders)
- c. MPS and demand uncertainty
- d. Lead times and planning horizons
- e. Safety stock and safety lead times

4.2.1 Lot Sizing and Rescheduling Rules

MRP systems suffer from a combination of the variables noted above. However, of all the variables, lot sizing and rescheduling are fundamental issues in MRP and as such much of previous research is in these two areas. Clarke (1988) noted that there are well over 20,000 articles written on this subject. An analysis of a sample indicated that there is a considerable amount of conflict in the findings between MRP researchers and MRP practitioners. In view of this fact it was considered prudent to reevaluate some of the work in this area in detail and compare it with JIT philosophy. The findings are discussed separately in the succeeding two chapters.

4.2.2 MPS and Demand Uncertainty

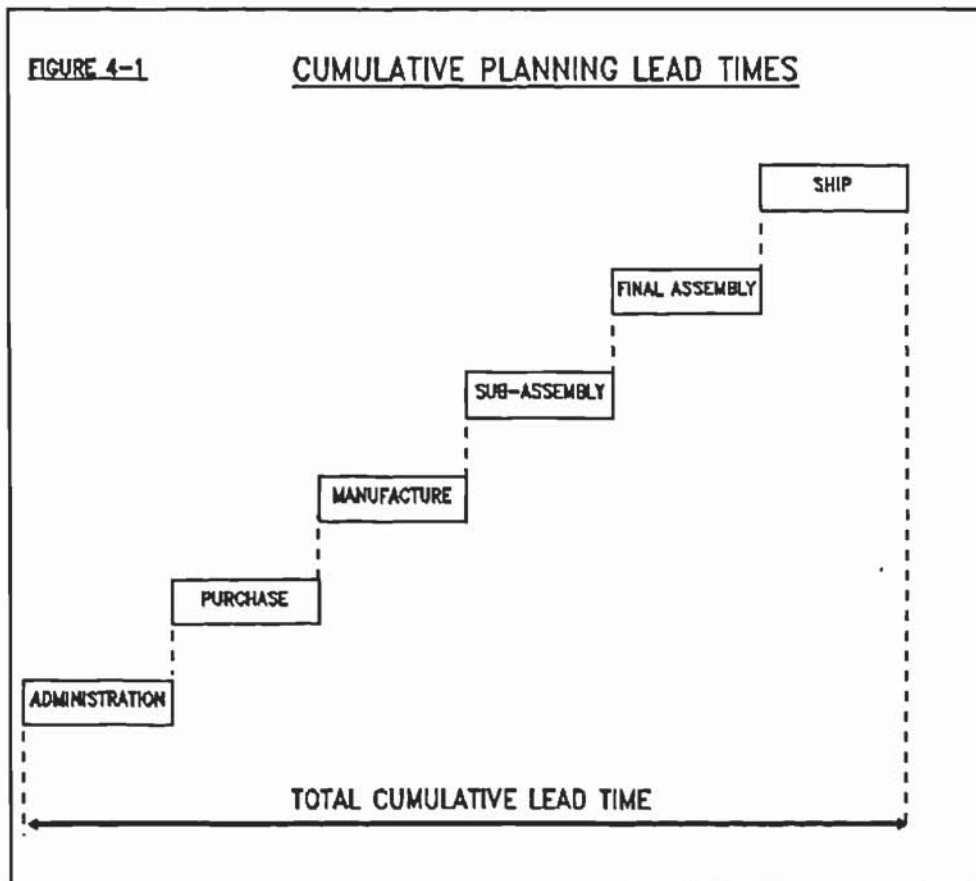
The MPS (Master Production Schedule) is a finished product plan specifying the quantities of the individual product to be manufactured in each time period. While many believed that the MPS could and should be held firm, modern business pressures have created a degree of demand uncertainty (discussed in chapter 3). The extent and nature of demand uncertainty is determined both by the external and internal factors. External factors include cancellation of customer orders, change in customer specifications, change in either timing or quantity of customer orders etc., which lead to changes in the MPS.

Internal factors include scrap uncertainty, quality uncertainty, supplier delivery uncertainty (both in timing and quantity), inventory record inaccuracy etc., which again ultimately cause a change in the MPS.

Changes caused by either an internal or external change reflect the dynamics of the real world and cannot be ignored by the MPS or MRP.

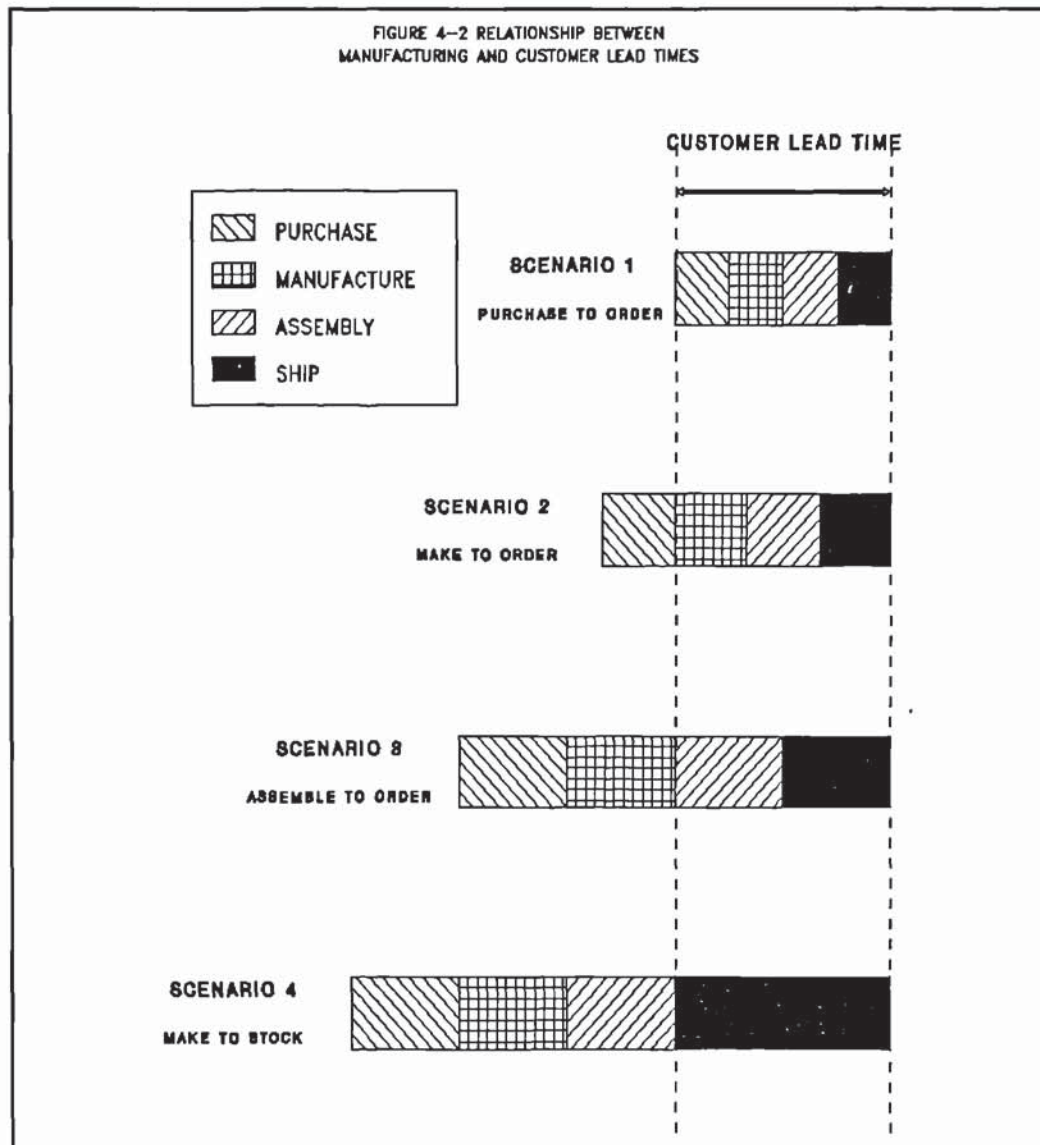
4.2.3 Lead Times and Planning Horizons

Lead times are at the very heart of MRP. It is through lead time offsets that production and purchasing order schedules are created. Consequently, the cumulative lead time of a product affects the MPS planning horizon and MPS stability. (Figure 4.1 shows the cumulative lead time of a product).



The length of the planning horizon should be at least as long as the largest cumulative lead time so that the lowest level parts can be properly procured. The length of the planning horizon directly affects the extent of demand uncertainty (or MPS stability). This is because the customer lead time is invariably much shorter than the total manufacturing lead time. (Customer lead time represents the time between receipt of a firm customer order and the required delivery date.) Consequently the MPS will have to be formed from a combination of 'firm' customers orders and forecasted future demands. A forecast will mean a forecast error. Therefore, the greater the

difference between the customer lead time and the manufacturing lead time, the larger the forecast error. Figure 4.2 depicts the typical relationships between manufacturing and customer lead times.



Scenario 1 - Purchase to Order

Scenario 1 represents the situation where the customer lead time is within the total product lead time. Consequently, both purchased and WIP orders can be initiated against firm demands. The probability of demand uncertainty and thus rescheduling is at a minimum.

Apart from the bespoke jobbing/contract type of business, where the customer is prepared to wait for the product, scenario 1 is rare in practice. For more standard products, even the best Japanese firms with continuous focus on cycle time reduction cannot achieve such a short turnaround time. Even if this is possible, competition will force the manufacturers to offer still shorter lead times and consequently force the product lead time to slip outside the customer lead time. Whilst, obviously work should be done to reduce lead times to the point where, as an ideal, one can trigger procurement on receipt of a firm customer order, this is only feasible as part of a long term commitment to flexible, short-cycle manufacturing. For the foreseeable future, some degree of forecasting will be needed to initiate procurement and manufacturing; consequently a degree of demand uncertainty will always be present.

Scenario 2 - Make to Order

Scenario 2 represents the case where the manufacturing, assembly and shipping lead times lie within the customer lead time, but the raw materials do not. Thus some element of forecast demand must be used to initiate raw material purchase.

Scenario 2 is representative of IBM Havant. Their total manufacturing and assembly times can be measured in days which is well within the normal customer lead times. However, their vendor lead times are much longer - months rather than days. Therefore forecasting is necessary to initiate purchasing. To prevent the demand instability being passed onto their suppliers, the MPS is frozen at the front end. However, this method ignores the dynamics of the manufacturing process and invariably results in either excess inventory or shortages.

Similarly, to minimise the disruption to their own production, IBM must also freeze its customer changes to a similar frozen zone. But with modern market pressures, discussed in chapter 3, IBM can no longer afford to freeze customer changes. To meet this challenge IBM has begun improving their own internal processes to accommodate customer changes right up to the point of shipping. While IBM is becoming more responsive, IBM's vendors cannot offer the same degree of flexibility. Therefore a solution is required which can maintain responsiveness but reduce the

limitations of long purchasing lead times i.e. meet the conflicting objectives of flexibility versus stability. This will be discussed in the context of an integrated strategy in chapter 7.

Scenario 3 - Assemble to Order

Scenario 3 represents the case where only the assembly and ship lead times fall within the customer lead time. Consequently, both raw materials and manufacture must be initiated against forecast demands.

Scenario 4 - Make to Stock

Scenario 4 represents the case where all the operations are outside the customer lead time. Consequently, to meet customer service, demands must be met from stock.

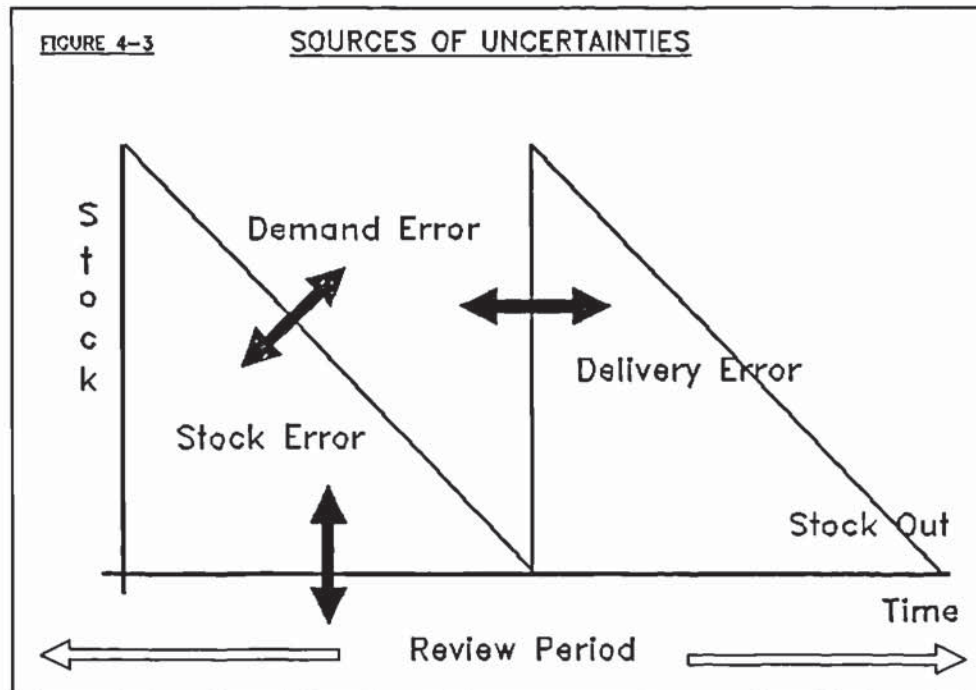
4.2.4 Safety Stock

MRP systems are designed for a deterministic environment (i.e. perfectly known demands). As discussed earlier, demand in practice is uncertain, whether resulting from external or internal factors. This can result in poor customer service levels. The common practice is to use either safety stock or safety lead time to protect against this problem.

Safety stock is generally used at the finished product level to protect against variation in forecasted demands, at the raw materials level to protect against fluctuations in the component supply, and at the sub-assembly level to protect against variations in service requirements.

There are numerous strategies for setting safety stock. Statisticians, for example, recommend that safety stock should be set against historical demand forecast errors. The mathematical formulas are often complex and in practice many firms do not or cannot measure forecast errors - at least not at the part number or sub-assembly level. Also, the method for setting safety stock has to be modified to account for various other errors such as scrap, loss, component commonality, delivery uncertainty etc., which occur in practice, giving even more complex statistical formulae. All the

various sources of uncertainties can be categorised into three logical groups as shown in Figure 4.3.



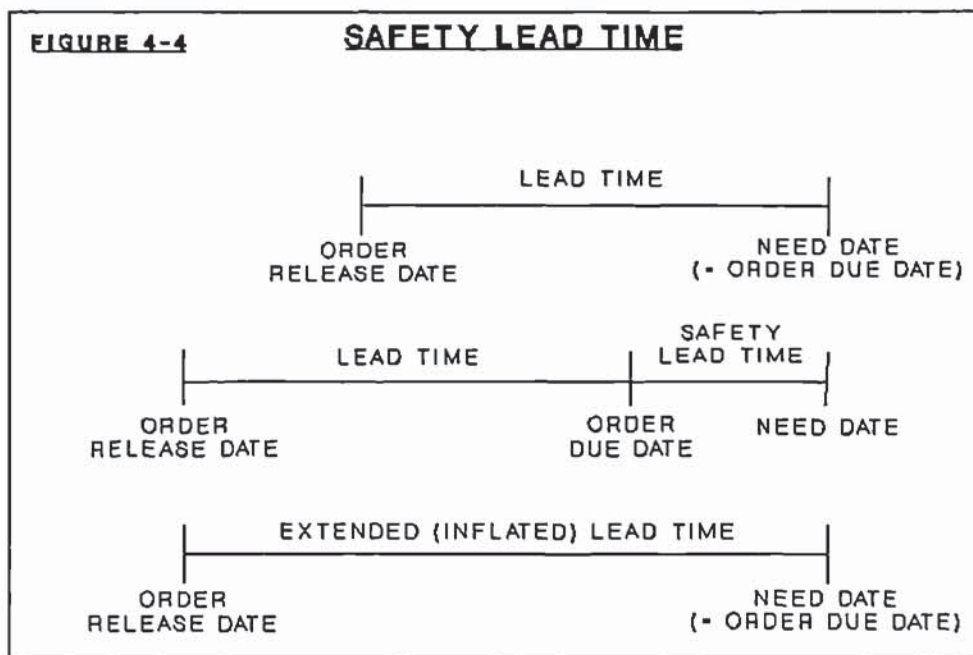
In practice, there is no systematic method of setting safety stock. This observation is supported by Wemmerlov (1979), who from his limited survey found little evidence that safety stock was set using formal procedures and statistical analysis - he concluded that the analysis is more a "gut feeling". From experience it seems that little has changed and it is still a common practice to set "blanket" safety stock according to the Pareto classes as discussed in chapter 2.

The problem with blanket protection is that for a given inventory investment some items are over protected whilst others suffer from shortages (under protection). To maximise service it is common sense to switch some of the protection from the less critical items to the more critical items. But in practice, this is difficult to achieve because:

1. There is usually no monitoring of how much of the safety stock is actually used.
2. There are few methods described in the literature which are able to take account of all the different variations acting together i.e. demand error, delivery variation, and stock uncertainty.

4.2.5 Safety Lead Time

The idea of safety stock can be extended to include the concept of safety lead time. By using this technique the order is launched early by an amount equivalent to the safety lead time. This technique brings the item into stock earlier than the true date needed for the assembly. However, there is much confusion over the use of safety lead time and inflated lead time. An inflated lead time simply extends the item's lead time, and thus launches the order earlier but the due date of the order remains unchanged. Figure 4.4 demonstrates the fundamental difference between safety lead time and simply extending the lead time.



From discussions and literature search it appears that few MRP users and researchers appreciate the subtle difference between inflated lead time and safety lead time. Although this distinction at first sight appears pedantic, the two have quite different

effects. For example, inflated lead time results in an order being launched early, but the due date would not change. If a priority scheduling rule is in operation, performance to due date would not be enhanced. However, adoption of due date offset (safety lead time) would affect the priority scheduling rule and an improvement in due date performance could be expected. In operational terms, expanding the item's lead time will not result in improved performance because the due date remains unchanged.

The safety lead time approach is used at IBM Havant. The use of safety lead time will, of course, increase the inventory level (because inventory is brought in earlier than the true need date), and thereby cost money. A problem with using safety lead time is that it leads to an increase in the planning horizon and thereby increasing the exposure to demand uncertainty. Whether this is sufficient to counter the advantage of safety lead time will depend on the relative strengths of the two effects.

There is little research material comparing the use of safety stock and safety lead time. Research that has been carried out shows conflicting findings: Whybark & Williams (1976) recommend that safety stock should be used to deal with quantity uncertainty, while safety lead time should be used to counteract uncertainty in timing. On the other hand in a study by APICS (1977) it was found that safety lead time generally leads to better results than the use of safety stock in MRP. The only consensus of opinion emerging from previous research is that both techniques should be used with caution and regularly reviewed. Further research is required to see the effects of both these policies in real systems.

4.3 Summary

The MPS (Master Production Schedule) is the most critical input into MRP. The MPS reflect the dynamics and uncertainties of the real world which ultimately leads to MRP nervousness - which is one of the major causes of MRP failure. The stability of the MPS is affected by lead times; therefore the policy to reduce lead times should form a significant part of any manufacturing strategy.

The degree of nervousness is also affected by the design of lot sizing, rescheduling, and safety rules and parameters. While there is a lot of research in lot sizing and rescheduling rules, a brief analysis indicates that it is of limited practical value. Because it is central to this research, a comprehensive review is presented in the following two chapters.

On the other hand, research in safety stock and safety lead times indicates that safety parameters are not set systematically. Current methods take little account of many sources of variations in the demand and supply of components. People who do use safety policies generally use blanket protection which proves very cost ineffective. Furthermore, the effectiveness of safety stock and safety lead time to reduce MRP nervousness is questionable. A further discussion is held in chapter 6 later.

Chapter 5

Review of Research in Lot Sizing

5.1 Introduction

Lot sizing is one of the most renowned issues in production planning and control. It dates to 1915, with F.W.Harris, who developed the concept of the 'Economic Order Quantity' (EOQ). Although lot sizing is by far the most widely researched area in MRP, it is often misunderstood in the design of ordering policies.

Much of the work is based on refining the original EOQ model. The goal of EOQ is to minimise the total cost by balancing the cost of holding inventory against the cost of ordering (or setting-up). A comprehensive review indicates that while research in lot sizing has been interesting, much of it is of limited practical value in light of the benefits of JIT. JIT underscores the importance of low inventory which runs counter to the cost-balancing approaches of the EOQ which assumes that the costs are fixed and cannot be improved upon. This chapter draws together some of the limitations of research in lot sizing rules.

5.2 Categories of Lot Sizing Techniques

All the lot sizing techniques can be conveniently categorised into three major groups:

- a. Fixed Quantity,
- b. Fixed Period (Coverage),
- c. Dynamic Lot Sizing (batching) rules.

As the name indicates, the 'Fixed Quantity' rules essentially order items in fixed batch sizes. This is simply a size related technique where the batch size is either determined by physical constraints such as packaging or more typically by "economic" order calculations.

The 'Fixed Period' rules calculate a batch size by batching the net requirements for a given period ahead. This is known as 'Coverage' and the coverage period can be based on an "economic" period calculation or a simple convenient repetitive cycle. This is effectively a time related technique where batches are released at uniform or regular intervals.

With 'Dynamic' batching rules, an algorithm attempts to calculate the optimum schedule which minimises the total operating costs over a planning horizon. Both the batch size and the coverage period are variable.

Table 5.1 lists some of the more commonly found rules in MRP within each of these three categories.

Table 5.1 - Lot Sizing Rule	
Category	Techniques
Fixed Quantity	Economic Order Quantity (EOQ) Fixed Order Quantity (FOQ)
Fixed Period	Fixed Period Quantity (FPQ)* ¹ Periodic Order Quantity (POQ)* ²
Dynamic	Lot for Lot (LFL)* ³ Least Total Cost (LTC) Least Unit Cost (LUC) Part Period Balancing (PPB) Silver-Meal (SM) Wagner-Whitin (WW)
*1 - Also known as 'Periodic Batch Quantity' (PBQ).	
*2 - Periodic order quantity is very often used to mean fixed period quantity in industry. But strictly speaking POQ is based on the EOQ calculation.	
*3 - Although the LFL is classified as a dynamic lot sizing rule, it is in effect not a lot sizing rule at all. It follows the demand pattern to eliminate inventory i.e. LFL is true JIT ordering.	

5.3 EOQ Based Techniques

With dynamic techniques (except LFL), the criterion for defining optimal decisions is essentially the same as that used in the original EOQ model which is discussed in detail later. In brief, the EOQ is calculated by using the average demand over the planning horizon. If the demand during a period exceeds the total planned inventory (on-hand plus planned orders), then an economic order is planned. Each new technique incorporated new simplifying assumptions and each proponent claimed their technique to be superior than the previous one.

The periodic order quantity (POQ) is a second EOQ based technique that calculates the economic time between orders - the lot sizes change but the time between orders remains fixed.

The least total cost (LTC) method is based on the rationale that the sum of inventory carrying costs and ordering costs for all the lots within the planning horizon will be minimised if these costs are as nearly equal as possible to the classical EOQ approach. Silver-Meal (SM) selects the lot size such that the total cost per period is minimised. Thus, the demands from consecutive periods are accumulated into a lot so that the average total cost per period (total cost is divided by the number of periods included in the lot) is minimised. This procedure is repeated for the entire planning horizon. The Least Unit Cost (LUC) technique is identical to SM except that the average total cost per unit (total cost is divided by the total demand quantity) is minimised.

The Part-Period Algorithm (PPA) calculates the economic part-period by dividing the ordering cost by the inventory holding cost per part per period.

The Part-Period Balancing (PPB) rule is identical to the LTC method except that it attempts to improve the total cost by using "look ahead/look back" adjustment. The adjustments are made if the total cost is improved. It looks ahead or back to at least two periods to determine if large demand periods exist.

The Fixed period quantity (FPQ) and Lot-For-Lot (LFL) rules are not based on the economic order principle. By the Lot-For-Lot rule, orders are placed for each non-zero demand period. The FPQ routine is simply a "weeks-of-supply" method. As soon as the need for an item is identified, this period's requirements plus a user defined number of future periods' requirements are added together into a lot size. A simple example is shown below (Example 5.1):

Example 5.1 - Fixed Period/Periodic Order Quantity Rule

Lead Time = 0, On-Hand Stock = 0, Order Cycle (Lot-Size) = 3 Weeks

Period (Weeks) :	1	2	3	4	5	6	7	8	9	10	11
	--	--	--	--	--	--	--	--	--	--	--
Requirements :	4	2	5	2	6	4	8		6	9	7
Planned Orders :	11			12			14			16	

These are but only a few of the most researched techniques. There are new ones being published each year, e.g. Freeland and Colley (1982), Bahl and Zionts (1986), Jacobs and Khumawala (1987) etc... Each new research effort adds a new dimension to the previous techniques, but as will be shown, they all still carry the inherent problem of the EOQ. They have also overlooked the benefits of the JIT philosophy.

Of the three categories, research focus has tended to be on dynamic rules. This is probably because they present the most interesting mathematical challenge to academics. Details of all these techniques are covered by Orlicky (1975), New (1974), and Silver and Paterson (1985).

5.4 Development of Lot Sizing Techniques

The original EOQ model is not suited to MRP. With the advent of MRP, the EOQ rule was modified over time to group the time phased requirements into a schedule of orders. In 1958, Wagner and Whitin first developed a dynamic version of the EOQ model that guaranteed an optimal solution (in terms of minimising the total cost of carrying inventory and ordering). The technique related lot sizes to short term fluctuations in demand over a finite planning horizon.

Despite the promised superiority of this algorithm, it received extremely limited acceptance in practice. The main reasons were attributed to its complexity which made understanding difficult for the practitioner. From a practical point, the computational effort was well beyond the capability of the technology at the time. Ignoring technology, a much stronger criticism today is the fact that a well-defined ending point for the demand pattern is not feasible in a real inventory system.

The following years saw a plague of approximating (heuristic) techniques and research on minimum planning horizons. Researchers were naturally intrigued by the Wagner-Whitin technique. They sought to capture the benefits of the Wagner-Whitin technique whilst minimising its limitations. Individuals such as De Matteis and Mendoza (1968), Eppen et al. (1969), Gorham (1968), Silver and Meal (1968), Blackburn (1974), Kunrueuther (1973, 1974), Lundin and Morton (1975), Quaye (1979), Karni (1981), Aucamp and Fogarty (1982) amongst many others have suggested various decision rules.

5.5 Lot Sizing in a Deterministic Environment

Dynamic lot sizing techniques such as Wagner and Whitin concentrate on minimising the total costs of an item in a deterministic demand pattern over a finite horizon. There are two arguments against these assumptions, first, in practice, decisions are usually made on a rolling schedule basis. This means the replenishment quantities are calculated over the entire planning horizon, but only the imminent, or first period, decision is implemented. At the next MRP run, new (or improved) information is appended to the horizon and the next imminent decision is implemented and so on.

A second deficiency is the assumption of deterministic demand. In a real MRP system, there is always uncertainty in demands and therefore the first period lot sizing decision is often based, or partially based on a forecast. This implies forecast error. In view of this, the validity and claims made for dynamic techniques become questionable. The implication of demand uncertainty in a rolling schedule environment is that any solution loses its 'optimality' as soon as it is implemented, thus questioning the benefits of such complex dynamic techniques.

5.6 Lot Sizing in a Rolling Schedule Environment

Baker (1977) was one of the first to realize the necessity of using the rolling schedule approach. He investigated the length of planning horizon and rolling schedules under time varying but perfectly known demand. The next few years saw a cascade of work on this subject, e.g. Blackburn and Millen (1980), Carlson et al. (1980), Chand (1980), with each researcher making more assumptions and adding additional parameters to the algorithms. The performance of the dynamic heuristics appeared to be inconclusive under the rolling schedule environment. Blackburn and Millen (1979) captures the essence of the collective findings - referring to these heuristics, they say:

"...the performance advantage shrinks dramatically under rolling schedule conditions and yet the computational costs remain".

This inconclusive finding further questions the validity of ordering heuristics. The only common agreement is that rolling schedules have a considerable influence on the cost effectiveness of lot sizing heuristics. Perhaps the most conclusive finding is that the minimum planning horizon should be at least as long as the cumulative lead time of the product.

Another point to note is that all these models were developed using only synthetic data with very simple product structures and simple demand patterns. Therefore another justifiable objection is the validity of such simple product structures and demand patterns. In practice both are fairly complex.

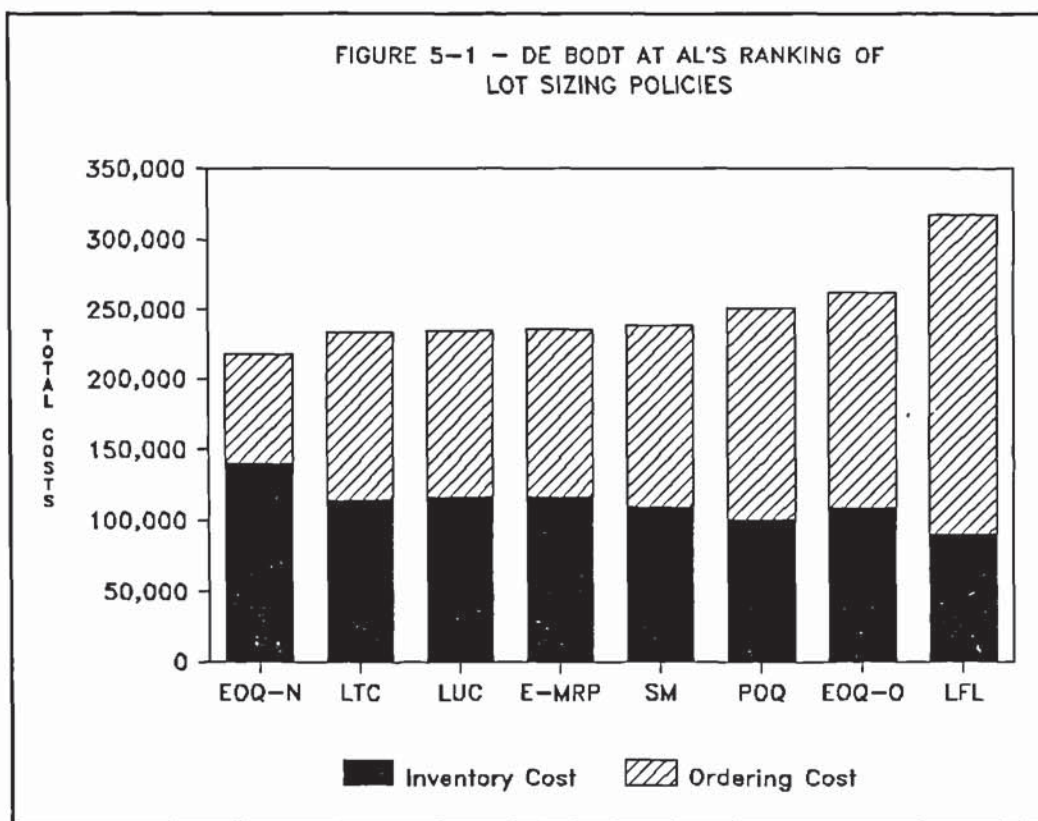
5.7 Lot Sizing and Demand Uncertainty

Research investigating the combined effect of demand uncertainty and rolling schedules on lot sizing did not begin until 1983. The first researchers to realise the importance of this issue was De Bodt et al (1983). Their work was the first to use real life data. They evaluated the relative merits of 8 lot sizing rules using real end-products and changing master production schedules. The rules evaluated were:

1. the original Economic Order Quantity (EOQ-O),
2. an updated EOQ (EOQ-N) - i.e. the ordering and holding cost were revised,
3. MRP adjusted EOQ (E-MRP) - i.e. the lot size is rounded up to satisfy the next requirement,

4. Periodic Order Quantity (POQ),
5. Least Total Cost (LTC),
6. Least Unit Cost (LUC),
7. Silver-Meal (SM),
8. and Lot-For-Lot (LFL).

Various degrees of forecast errors were introduced in the master production schedule. They produced a number of important results, one of which was a ranking of the 8 rules in terms of total annual costs using traditional standard costing measures. Their ranking is as shown in Figure 5.1.



As might have been expected, they found that the Lot-For-Lot was ranked the worst in terms of the traditional costing method. But a more surprising finding was that there is negligible difference between the dynamic lot sizing rules tested. The performance of the dynamic techniques was also significantly poorer than the updated EOQ technique. This leads to the fundamental question of whether the lot sizing techniques, which were essentially developed for MRP systems (e.g. LTC, LUC etc.), are really as good as their proponents claim. Industrial cases are always

dynamic and uncertain, whereas the lot sizing techniques for MRP are tested under static conditions with perfectly known demand.

A point to note from Figure 5.1 is that although the updated EOQ (EOQ-N) performed the best in terms of total costs, the inventory has increased. How does one convince management to accept the resulting increase in inventory? This problem arises because optimisation techniques act as local optimiser and consider each part number in isolation (micro performance) with no regard to the overall inventory performance (macro performance). The increase in stock holding costs generated by 'optimal' lot sizing represents additional cash outlay. This is a significant point and should be borne in mind by MRP implementors when considering lot sizing parameters.

In brief, work of De Bodt et al., which was based on a single level BOM structure similar to the IBM situation, found that the cost differences between different techniques becomes insignificant in the presence of forecast errors (even small forecast errors) and all the lot sizing techniques (except for LFL) seem to give similar results. None of the techniques perform consistently better and they have suggested that it might be better to use simple techniques based upon fixed quantity or fixed time instead of the more sophisticated MRP dynamic techniques.

5.8 Validity of Standard Costing in Lot Sizing

As mentioned earlier, most lot sizing techniques are based on the basic EOQ model and depend on balancing the inventory holding and ordering (or set-up) costs. The simple EOQ formula is:

$$EOQ = \left[\frac{2 * \text{Ordering Cost} * \text{Annual Demand of Item}}{\text{Inventory Holding Rate} * \text{Unit Cost of Item}} \right]^{1/2}$$

There are a number of assumptions made by the EOQ based models, (Details of these can be found in Lewis (1981), New (1974), Silver and Paterson (1985)). However, the holding and ordering costs, together with the cost of running out of stock required

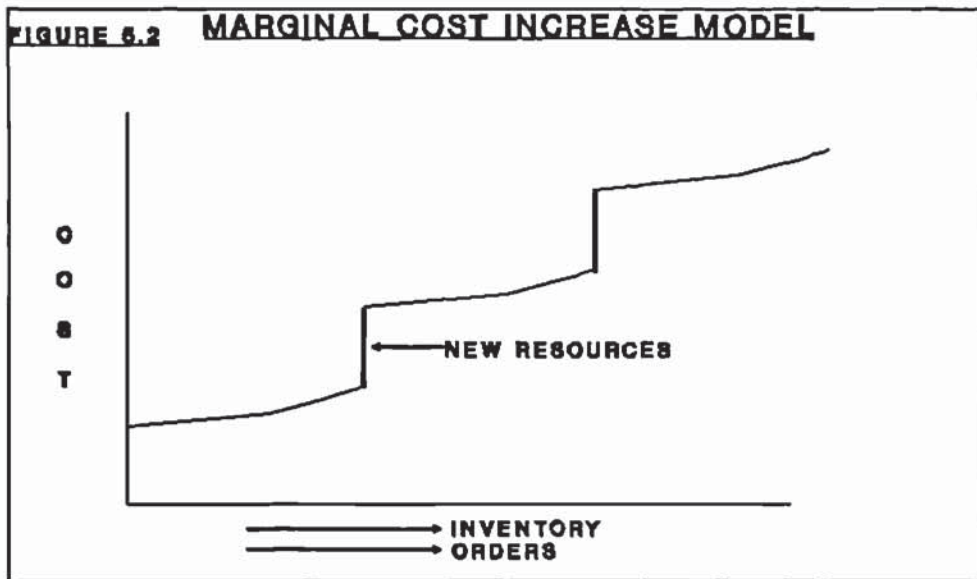
to operate these heuristics are difficult to determine in practice. This being so, the EOQ formula is not very sensitive to errors in the estimation of costs. What is more critical is the assumption that the costs are linear, i.e. it costs twice as much to double the number of orders, or to double the amount of inventory. This assumption is rarely true in practice. For instance, what is the cost of placing one more order? If no more people are hired as a result of the additional order, then the cost is negligible: the cost is that of paper, which is insignificant.

Similarly, what is the cost of holding inventory? Some speak of 20, 30 or even 40 percent of the unit cost. Inventory holding cost, in addition to the opportunity cost, includes handling, moving, storage, counting, insurance, risk of obsolescence, spoilage, and shrinkage; but these costs are not strictly variable with inventory levels. For instance, storage costs are fixed until a new warehouse is required. What is the opportunity cost? If a company is cash rich, it could be the returns from other more profitable opportunities. If it is cash poor, then it could be the cost of avoiding bankruptcy. Many other so called variable costs are actually fixed in practice, at least over the short time horizon.

These points have a profound effect on the validity of the previously unquestioned lot sizing studies. Recognising this, St John (1984) and Aucamp (1984), in separate articles voiced concern over the traditional lot sizing research. Their argument continues to the effect that only marginal ordering and inventory holding costs should be considered in determining lot sizes.

5.8.1 Marginal Costing

The principle of the marginal costing is that the cost to place one more order should be extremely small relative to the average cost. The justification for this view is that staff are already being paid their salaries, the office furniture is there whether one more order is placed or not, etc. The effect of marginal order costs is that it will always encourage smaller lot sizes - precisely the argument for JIT. St John (1984) argues that these are sunk costs and are not relevant to the lot sizing decision. The principle is shown in Figure 5.2.



5.8.2 Rescheduling Costs

Another point which researchers have consistently overlooked is the fact that the major cost incurred by the supply function is not in placing orders but in negotiating schedule changes and cancellations. Negotiating changes is the major part of a buyer's activity. Schedule changes and cancellations incur large penalties which in the case of the industrial partner have over-shadowed the cost of ordering. As will be seen from the results in chapter 12, smaller orders leads to a reduction in reschedules. Hence there are much more wider benefits of smaller lot sizes which traditional lot sizing research have not captured.

5.9 Lot Sizing as a Source of MRP Nervousness

MRP nervousness stems from the top level (end-item) schedule changes (e.g. customer needs change) and/or from changes in inventory status (e.g. counting error, scrap etc.). Dynamic (optimal) lot sizing rules exacerbate the nervousness through the system via the bills of material explosion. Wemmerlov, and Carlson et al. (1979) were the first to recognize this undesirable property: every time the pattern of requirements change, the corresponding orders change. Not only do dynamic lot sizing techniques perpetuate nervousness but the reschedules are often the reverse of what logic would suggest. This was first discussed by Mather (1985).

5.10 Effect of Lot Sizing on Overall system Performance

Lot sizing methods are evaluated on the basis of a few carefully selected items treated independently. However, the final decision on the "best" method is applied en masse. The effect of all the items considered together (macro performance) is not known prior to implementing the decision. The effects of the decision can lead to an increase in the total inventory level as discussed earlier. The consequences may be disastrous - crippling cash flow, bursting warehouses, erratic demands on suppliers etc.

5.11 Lot Sizing Techniques Commonly Used

In a survey by Wemmerlow (1979) he found that of the available techniques, 'fixed period quantity' (sometimes called periodic order quantity) was the most widely used. This was followed by 'lot-for-lot' and then 'fixed order quantity'. A more recent survey by Haddock and Hubicki (1989) found similar results. The most surprising finding was that the complex dynamic techniques such as least order cost and least unit cost etc., which are favoured by researchers are rarely used in practice. There are several reasons for this paradox.

First is simplicity itself. Analysers, buyers, and production controllers etc. need to understand the schedules that are generated. They need to understand how and why the lot size quantities are what they are. Simple techniques such as lot-for-lot and fixed periods can easily be interpreted. Another reason is user acceptance. Users are more likely to accept the recommendations if the order sizes match their manual calculations and business logic as discussed in chapter 2.

5.12 JIT Purchasing

As the Japanese have proved, there are many advantages of smaller lot sizes; such as earlier identification of quality problems, reduction in material handling and space etc. The traditional EOQ models are not useful for this purpose because of their singular concern for minimising short term costs at a part number level (micro level) rather than the whole system (macro level) - a point raised in chapter 1.

The implementation of JIT purchasing concepts will serve to decrease the operating cost parameters of the inventory system, i.e. the cost of order processing, receiving, inspection and storage, etc. For example, once long term contracts have been established and blanket orders are placed then the costs in each delivery cycle will be greatly reduced since the cost associated with formal purchase order releases, acknowledgements, invoicing etc., will be eliminated. In each cycle the costs will be limited to sending the "pull" signal, maintaining the order file, physical handling, and perhaps inspection and transport. Thus the order cost parameter will be much smaller than that in the traditional EOQ model. In addition technology development in EDI (Electronic Data Interchange) should make ordering costs a negligible factor in the overall material logistic equation.

5.13 Summary

Lot sizing in MRP is often misunderstood even though it is one of the most researched topics. Lot sizing research is based around the EOQ model. Researchers have proposed numerous "optimisation" models, but users are only implementing MRP systems which use simplistic approaches to establishing the order size. There are several reasons for this. The most profound is that users recognise the complexity of the lot-sizing decisions and perhaps even question the feasibility of determining "optimal" lot-sizes.

Early developments of the lot sizing heuristics were motivated by the poor speed of computer processing. Simplifying assumptions were made to improve run-time performance. With advancement in technology, such factors are no longer important; however, the original limitations are still embedded into recent research. Criticising the EOQ models is not to say that lot-sizing is invalid, but rather for a long time research has been looking at the wrong problems. Rather than optimising inventory decisions, the emphasis should be on managing the inventory system.

JIT advocates the reduction and eventual removal of inventory wherever possible. This philosophy runs counter to the historical EOQ lot-sizing approaches. Both management and researchers have fallen into the trap of believing that there is an

optimum cost. Rather than examining ways in which the parameters of a model (inventory holding costs, ordering costs, and demand) can be changed, model users and model developers have assumed the costs to be given. Existing research approaches, moreover, have merely attempted to modify the EOQ model to meet the specifics of the real situation (for example, by considering demand variability, planning horizons, etc.) rather than questioning the underlying philosophy of the model.

Finally, a concern that needs to be addressed in order to properly manage the lot-sizing decision is determination of the proper performance measurement system. Working towards JIT means that one can no longer assume the parameters of the system to be given, but rather that one has control over them. These are philosophies that change the goal of the system from that of optimising the given system to a more proactive attempt to manage and change the system where necessary. These points will be addressed in later chapters.

Chapter 6

Review of Research in Rescheduling Rules

6.1 Introduction

The so-called rescheduling capability is a principle strength of MRP systems. Rescheduling realigns the due dates with the need dates and maintains order priority. However, the resultant frequent disruptions of orders is a major operational problem. This problem is generally referred to as 'system nervousness'. The objective of MRP rescheduling rules is to maintain order priority without exposing the system to excessive shocks (nervousness) due to frequent rescheduling. This chapter evaluates the research in reducing nervousness.

6.2 Definition of MRP Nervousness

MRP systems were originally designed for a deterministic environment i.e. known demands. In practice demands for end items are almost always uncertain and subject to frequent changes. This leads to order instability, or nervousness. A more rigorous definition of nervousness described by Kropp et al. (1983) is:

"...the frequent changes in due dates or order quantities for either purchased or manufactured items."

6.3 Effects of Nervousness

Exception reports present several problems. Their volume is indicative of the degree of nervousness in the system. The number of reports generated depend on the frequency of MRP regeneration and the degree of dampening in the system. Since planning resources are not unlimited, high volumes of such reports are troublesome and not all exceptions may be reviewed and acted upon. With large volumes of reschedule notices, it is likely that some of the more critical exceptions may not be dealt with in a timely manner, if in fact they are viewed at all. A similar view is expressed by Minifie and Davies (1986).

Another problem with exception reports is that the exact nature of the exceptions may not be readily apparent. This again brings the system into disrepute and valuable planning resources are further consumed to determine why the exceptions occurred.

Workers such as Mather (1977), Blackburn et al. (1985), amongst others have also noted that order instability is frequently an obstacle to effective MRP system implementation. In a 'nervous' environment, the frequent rescheduling of orders can undermine management's confidence in the system, depriving it of the resources needed for successful operation.

6.4 Causes of MRP Nervousness

MRP nervousness is caused by operating variables such as lot-sizing rules, or by some external environmental factors such as demand changes, and supply of components, etc., discussed in chapter 4. The level of MRP nervousness can usually be gauged by the volume of exception reports generated. Exception reports indicate that the previous schedule has changed. There are three basic types of exception reporting by MRP systems;

- a. rescheduling-in (expediting)
- b. rescheduling-out (delaying)
- c. cancelling

Reschedule-in messages are generated whenever the total planned inventory balance (on-hand inventory plus scheduled order receipt) is less than the immediate requirements. The converse is of course true for reschedule-out. A cancellation message is generated whenever the order cover (total planned inventory) is greater than the maximum permissible. Cancellation is an extreme case of a reschedule-out.

6.4.1 Demand Changes

Demand changes are for a number of reasons and are reflected in the master production schedule. For instance, the MPS may be modified several times prior to actual production to reflect customer changes, forecast updates, and engineering changes. The master production schedule drives the MRP. Thus a change in the MPS

propagates throughout the MRP resulting in exception messages at all levels.

Another factor affecting nervousness is the demand horizon. As new demands are rolled into the schedule (as discussed in sections 5.5 and 5.6), prior ordering decisions are subject to revision and, when altered, can propagate sequences of order changes to the next level down and so throughout the system. This factor was revealed by Blackburn et al. (1985).

6.4.2 Supply Variations

Variation in the supply of components cause changes in the scheduled order receipts. Variations are caused by several factors including inventory counting errors, a vendors ships short or late (or both), vendor ships wrong components, perhaps shipment includes defective items, lower yield than usual is realised (an important factor in the electronics industries) etc...

Clearly, such changes will cause MRP nervousness and many have tried to minimise schedule changes by simply holding safety stocks. But MRP maintains safety stock i.e. safety stocks in MRP are not nettable - so they only serve to protect against physical shortages rather than reduce nervousness. This point is discussed in detail in section 6.5.5 later. In chapter 10, a method is developed which will make use of the safety stocks to actually reduce nervousness.

6.4.3 Lot-Sizing

It is a common mistake to assume that MRP dictates how much and when to order. In fact, it tells neither. MRP tells what is needed and when it is needed; how much is ordered and when it is ordered to fill those needs is an open question after the MRP system has determined net requirements for each period. It is up to the lot sizing techniques to determine order placement and order quantity to meet projected requirements. However, any lot sizing that occurs below the top level of the product structure affects the lower-level requirements because of the time-phased explosion process. This phenomenon was first recognised and investigated by Wemmerlov et al. (1979).

It is well known that errors in the end-item forecasts cause schedule changes, or nervousness; but as is apparent from above and from discussions in chapter 5, the lot sizing effect is not as clearly understood, even today. As discussed in chapter 3 and 4, this is one of the reasons why little attention is paid to the selection of the ordering policies and parameters.

6.5 Strategies for Reducing System Nervousness

The problem of whether to reschedule or not has existed since MRP systems were first installed. According to Ho et al. (1986), the rescheduling capability of MRP is one of its most important functions and critical to successful operation. In practice, rescheduling is one of those difficult problems in production scheduling which according to the literature is not easily understood. Confusion increases exponentially with the volume of rescheduling notices, a sentiment first echoed by Campbell (1971).

Painful experience has shown that even in small systems the volume of exception messages is unmanageable. To combat the adverse effect of MRP rescheduling capability, experienced users have implemented numerous dampening mechanisms. A dampening procedure can be viewed as a filter which screens out insignificant rescheduling messages. The insignificant messages are those which will have little impact on due date performance. In contrast, the messages not eliminated by dampening filters are considered significant and should be implemented.

There are now many dampening rules available. Amongst the more widely found rules are:

- a. rescheduling costs
- b. lot-for-lot below the top level
- c. Freezing the master production schedule
- d. firming planned orders
- e. safety stocks/safety lead times
- f. some combinations of above

6.5.1 Rescheduling Costs

Between 1979 and 1983, Carlson et al. in conjunction with Kropp et al., produced a series of papers on the idea of incorporating penalty costs or rescheduling costs for changing a previously established schedule. They modified several dynamic lot sizing rules to include rescheduling costs and compared their performance.

The power of these modified algorithms is such that a decision to change the schedule is made when the joint consideration of ordering, carrying, and schedule change costs indicate that it is "economically" beneficial to do so. Thus, the approach attempts to strike a balance between the cost of nervousness and the cost of a non-optimal solution in determining the amount of nervousness that is economically tolerable. They showed that the performance of the modified algorithms were superior than the original algorithms.

However, many of their assumptions are questionable. For instance, they assume that the schedule "change costs" are perfectly known (and given) - surely a rather naive assumption. In practice, estimating the values of the change costs is difficult, indeed was found to be impossible in this research. Also such costs cannot be fixed. They should be varied to reflect the changing circumstances. For instance, the schedule change cost needed to prevent a loss of customer order must surely be different to that if one is simply making for stock.

Secondly, they assume that to reschedule an order is more costly than to cancel an order. This is clearly a ridiculous assumption. Anyone who has been in purchasing knows that a cancellation incurs a much higher penalty than a simple reschedule. This research found that to cancel an order, a vendor will charge for some, if not all the work done to that point, plus material costs. On the other hand, a schedule change will generally be accommodated by a vendor without a significant penalty.

Finally, the more severe criticism is the whole concept of optimization. All the algorithms minimise the total cost based on an expected actual demand pattern. This is rather a preposterous claim since the actual demands only become known sometime

after the decision has been implemented. Consequently, lot sizing algorithms cannot guarantee an optimal result because the demands used to optimise costs will invariably be different from the actual demands.

A decision to reschedule or not, based on the cost of reschedule is an attractive principle. However, such costs are difficult to determine in practice and this method is not widely used in industry. In light of these objections, the value of previous research is of limited practical value. In practice, managers would rather live with non-optimal but stable plans - a sentiment first voiced by Steele (1975). The main contribution of previous work is seen to validate the intuitively obvious notion that nervousness decreases as the cost of change increases.

6.5.2 Lot-For-Lot at the Top Level

This approach places orders in the same periods. Nervousness due to timing changes is limited; but a change in the order size cascade down to the next level thus exaggerating nervousness. It is as might be expected, the most effective rule for minimising inventory but the least effective for reducing nervousness. Therefore the objectives for implementing this policy must be clear.

Despite the tendency for this rule to enlarge the problem, it is one of the most widely used rules in practice. There are three main reasons why this technique is readily adopted:

- a. it minimises inventory
- b. it is simple
- c. it does not distort priorities

To compensate for the limitations of the lot-for-lot rule, many firms in practice use a combination of lot sizing techniques to reduce system nervousness. Research by Wemmerlov (1979) indicated that there is a clear tendency for companies to apply lot-for-lot to assemblies and subassemblies. This is so that true priorities are maintained for the assembly and subassembly schedules. Other batching techniques such as fixed order quantity and periodic order rules are used at the component level.

This approach reduces the number of orders and reschedules without increasing inventory by a significant amount i.e stability is achieved for a negligible increase in inventory.

Clearly, lot-for-lot is JIT production. However, recent workers such as Blackburn et al. (1986) have dismissed lot-for-lot as being cost ineffective based on the traditional costs of ordering, holding inventory, and cost of changing schedules. As discussed already, such costs are indeterminable in practice, thus questioning the strength of their argument.

6.5.3 Freezing the Master Production Schedule

The master production schedule may be altered to reflect either environmental (external) and system (internal) changes. Environmental changes are represented by demand uncertainty such as cancellation of customer orders. System changes represent internal changes such as scrap, late deliveries etc., (discussed earlier in chapter 4.2.2).

Both timing and quantity changes in the MPS are propagated through the MRP. One method to dampen the changes is to freeze the MPS. Although this is a very effective form of dampening, it does distort priorities right through the MRP system. If a company is building for stock then its effects are not so critical. However, if a company is building to order then this method can prove disastrous - the imbalance between the MPS and the true customer need date will lead to some dissatisfied customers and excess stock of other finished items.

There is little research investigating the effects of freezing the MPS. Further research in this area to see how priorities are distorted may be useful. Research is also required to see what population of the MRP users use this method.

6.5.4 Firm Planning Orders

This involves firming up planned orders - MRP systems treat firm planned orders as open orders i.e. it does not reschedule them. Generally, users only firm plan

purchased orders to stop the frequent changes being imposed on their suppliers. Again this is not supported by much research but it has the same effect as freezing the MPS.

6.5.5 Safety Stock and Safety Lead Time.

Several researchers, notably New (1975), Steele (1975), Whybark et al. (1976) and Kropp et al. (1979) have suggested that safety stock and/or safety lead time provide an indirect means of eliminating system nervousness. In a study by Whybark and Williams (1976), they reported that safety stock is intended to protect against demand quantity variability whilst safety lead time is preferred to buffer against timing uncertainty.

However, as Lowerre (1985) and Minifie and Heard (1985) noted, in an MRP system, safety stock is treated as non-existent during the netting process i.e. it is effectively treated as a phantom customer order and the MRP system always maintains the stock. Thus safety stock has no effect on dampening nervousness - a point made earlier in section 6.4.2. In practice, as Wemmerlov (1979) noted, there is widespread scepticism toward safety stock. Many companies are now aiming to reduce or completely eliminate it. The reason for the scepticism is that safety stock distorts the "true" priority whilst the replenishment order for the safety stock consumes invaluable capacity.

6.5.6 Management Programs

Dampening mechanisms distort schedule priorities. Therefore Mather (1977) questioned the benefits of dampening mechanisms. He suggested that instead of grappling with such mechanisms, energy should be directed to solving some of the physical causes of schedule changes. He suggested a number of management programs to 'cure' the nervousness in an MRP system. His suggestions can now be effectively thought of as being compatible with the JIT philosophy. He suggested programs such as quality control, vendor control and certification, and preventive maintenance. Although, at the time his suggestions were viewed with some scepticism, they are now considered to be the key to successful MRP operation.

6.6 Summary

Changes in the master production schedules and the use of lot sizing techniques cause schedule changes. Large volumes of rescheduling notices are disruptive and undesirable. The frequent rescheduling of orders is referred to as 'nervousness'.

Strategies and methods to reduce MRP nervousness are of wide interest and have attracted much research. However, the majority of the research concentrates on the schedule 'change costs' e.g. Carlson et al. (1979), Kropp et al. (1983) amongst others. Change costs are difficult to determine in practice and it is not surprising to find that such methods are not applied in practice. Many of the other dampening mechanisms suggested are not practical also, either because the parameters are difficult to determine or the mechanism distorts priority. Most users are simply concerned with how to stop insignificant reschedule messages. Insignificant messages are those which have little negative impact on due dates. However, simple methods are currently not available to dampen insignificant reschedules.

In general, research on rescheduling rules is of limited practical value. In discussing the multitude of factors affecting reschedules, Mather (1977) neatly encapsulated the users frustrations with researchers by stating that:

"...a much more productive approach is to reduce the number of reschedules down to those that are absolutely necessary, and then get prepared to handle those few."

This point will be addressed in chapter 9 where a simple method is developed to filter the insignificant reschedules as suggested by Mather.

Chapter 7

Strategy to Control and Integrate MRP

7.1 Introduction

Inventory reduction has received much attention over recent years. It is largely spurred by competitive influence from abroad by companies establishing JIT concepts. For some, MRP systems are still the only way to run a manufacturing operation successfully. Others quote the poor success rate of companies who have implemented MRP and put their total faith in the JIT manufacturing technique; but neither have enjoyed outstanding success in the US or the UK.

Although JIT is not a system, there appears to be a commonly held view in manufacturing industry that MRP is in direct conflict with JIT and that JIT will replace such systems. Having already looked at the deficiencies and problems of operating MRP, this chapter will define the role of MRP and JIT and explain how MRP can be integrated into the JIT concepts and philosophies to gain significant reduction in inventory and operating costs, and regain MRP control.

The strategy to control MRP and migrate from a typical MRP based ordering process to a JIT operation is illustrated using IBM Havant as a case study.

7.2 Efficiency and Costs

Efficiency of operation is the aim of any manufacturing system. Today, as discussed in chapter 3, competition in costs, product diversity, and customer service forces manufacturers to have flexibility. This has meant that efficiencies must be achieved by the elimination of waste rather than the traditional economy of scale offered by production of large batches. Many manufacturers are now implementing JIT programs to address every part of the organisation. The manufacturing aim is to reduce and eventually eliminate all forms of waste and inefficiencies from the manufacturing process. Ultimately, inefficiencies and waste manifest as cost. Therefore, the goal of

manufacturing must be to reduce cost - not inventory as is commonly believed, a point discussed in chapter 2.4.3.

Small-lot deliveries (reduction in inventory) facilitate the exposure and elimination of the inefficiencies and the waste that would otherwise continue to exist in the system under the pool of inventory. Typically, the costs associated directly with purchased items are:

- a. transport
- b. inspection
- c. receiving, handling, and storage
- d. administering the purchased orders etc.

These costs will obviously vary according to the number of deliveries and the lot-size. The magnitude and the rate at which these costs change will, however, depend on the extent to which the plant has made progress towards the JIT concept. Small lot-sizes will reduce inventories and the cost associated with high inventories; but with a traditional process it will inevitably increase the cost of transportation and order management (increasing the number of order recommendations will increase the number of reschedules, and the number of orders to track and maintain). Therefore a balance must be found between inventory and costs.

7.3 Impact of Reducing Inventory

To reduce inventory means increasing the number of order/delivery recommendations. Increasing the number of recommendations will subject more of the orders to change thus increasing system nervousness. This is the achilles heel in MRP. Also traditionally, it is believed that reducing inventory will reduce customer service and increase the production costs. The rationale is that the costs will increase because of the likely increase in the number of shortages resulting from a reduction of inventory. This will obviously be true if inventory is reduced haphazardly without detailed analysis.

7.4 Defining The Missing Link

It is clear that there exists a conflict. Inventory is required to maintain high customer service whilst MRP is required to schedule the wide range of products and process customer requirements. On the other hand, JIT is required to reduce costs; but according to IBM's JIT experts, to implement JIT/Kanban successfully requires demand stability (as discussed in chapter 2). Here lies the problem - how does one meet the conflicting objectives of flexibility and stability. These conflicting requirements can (as will be shown) be overcome with a well designed and integrated solution.

7.5 Integrated Solution

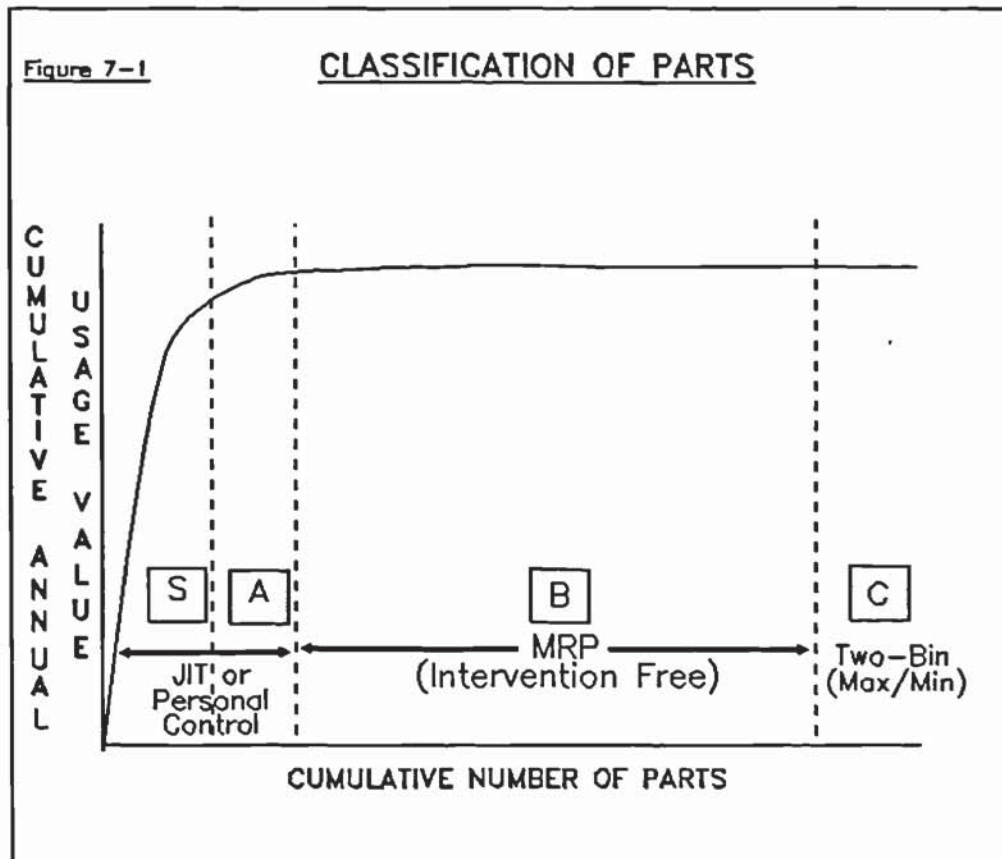
The term "integrated solution" is used rather than integrated system because systems are generally thought of as computer based. MRP by necessity is computer based, but computerised systems are not always necessary. For example, a manual two-bin system or Kanban can provide a highly efficient and cost effective solution for some parts of the total system. Also JIT is a philosophy and not a system. It is very people oriented and many activities are never likely to be fully computerised.

The design and choice of this solution will affect the cost of the total manufacturing system. The decision to the extent to which JIT concepts will be adopted must not be taken lightly. The benefits will accrue over a period of time and therefore the decision involves major commitments. In the meantime, there are simple steps which can be implemented to improve MRP performance and reduce total costs. As discussed in chapter 4, these steps include the choice of ordering, rescheduling, and safety stock policies. The optimisation of parameters within the framework of these rules will affect the MRP performance and the total operating costs.

7.6 Case Study

The potential for integration is illustrated by using IBM Havant as a case study. IBM Havant is mainly an assembly plant with over 90 percent of the parts bought-out. There are currently over 7000 part numbers maintained in the system of which just over 4000 are active.

In 1983 as a result of a competitive analysis, IBM Havant identified that the material supply and control process was a key cost lever. This was the impetus to reduce inventory and production costs. By early 1987, it had implemented a JIT pull process for the very key components supplied from several of its sister plants. Typically these are the very high technology (propriety technology) items such as 'logic' cards. These are essentially the very high value parts and are classified as 'S' (Super value class) items at IBM, purely for convenience. The 'S' class is simply a sub-set of the 'A' class used in the traditional ABC analysis. Figure 7.1 shows the Pareto distribution and the classifications of parts used at Havant.



The pull process called 'IPP' (Inter Plant Pull) decouples the planning system from the execution sub-system. Planning is carried out by MRP while the items are pulled as required by the production lines. Parts are pulled either weekly or more frequently depending on the material logistics involved. This process has made a significant

reduction in the plant's inventory holding.

At the other extreme, fastenings such as nuts, bolts, washers etc. - the 'C' class items (which are essentially the very low value but very high usage items), represented a significant administrative workload. In a bid to reduce administrative costs of maintaining such items Havant contracted out the maintenance of these (under a blanket purchase order) to a local vendor who tops the line bins daily. This is essentially a two-bin system.

The JIT/Kanban controlled items (the 'S' and 'A' classes) represent less than 5 percent of the parts and over 50 percent of the total inventory value. On the other hand the 'C' items represent about 4 percent of the total items and negligible inventory value. Thus the vast majority of the items are still planned and controlled by the MRP system.

The MRP controlled items, while still representing a significant inventory holding, however, constitute almost all of the purchasing workload - either in validating new order recommendations or reviewing and negotiating order reschedules and order cancellations. While this is a problem in itself, the more severe problem is the wide fluctuations in the actual numbers of notices generated each MRP cycle (run monthly because of the multi-plant nature of IBM's MRP system). The variable workload results in staff frequently having to work overtime and thus adding expenses. Obviously, the variation in the number of order recommendations affects the inventory levels and number of deliveries each cycle which in turn adversely affect the 'total acquisition costs' too.

The combined effect of poor MRP performance and the success of the 'Inter Plant Pull Process' prompted IBM Havant to extend the JIT purchasing concept to vendor parts in an effort to reduce costs. However, they soon learnt that the process would be very long with the number of items and vendors involved. Moreover it was found that it is not economical to pull every item. Consequently it was felt prudent to improve the MRP performance while evolving JIT and two-bin supplies. This is a

continuous process and the rate of migration is dictated by the ability to control MRP effectively. This was the challenge.

7.7 Requirements of the Solution

To meet the challenge the solution must meet the following requirements:

- a. reduce inventory while maintaining customer service
- b. aid in reducing operational costs
- c. reduce the magnitude of fluctuations in the volume of MRP recommendations and inventory levels
- d. reduce the overall volumes of reschedules
- e. facilitate JIT/Kanban implementation
- f. enable different business plans to be evaluated
- g. set appropriate parameters to meet the business plan
- h. the solution must be portable -i.e. applicable to other plants

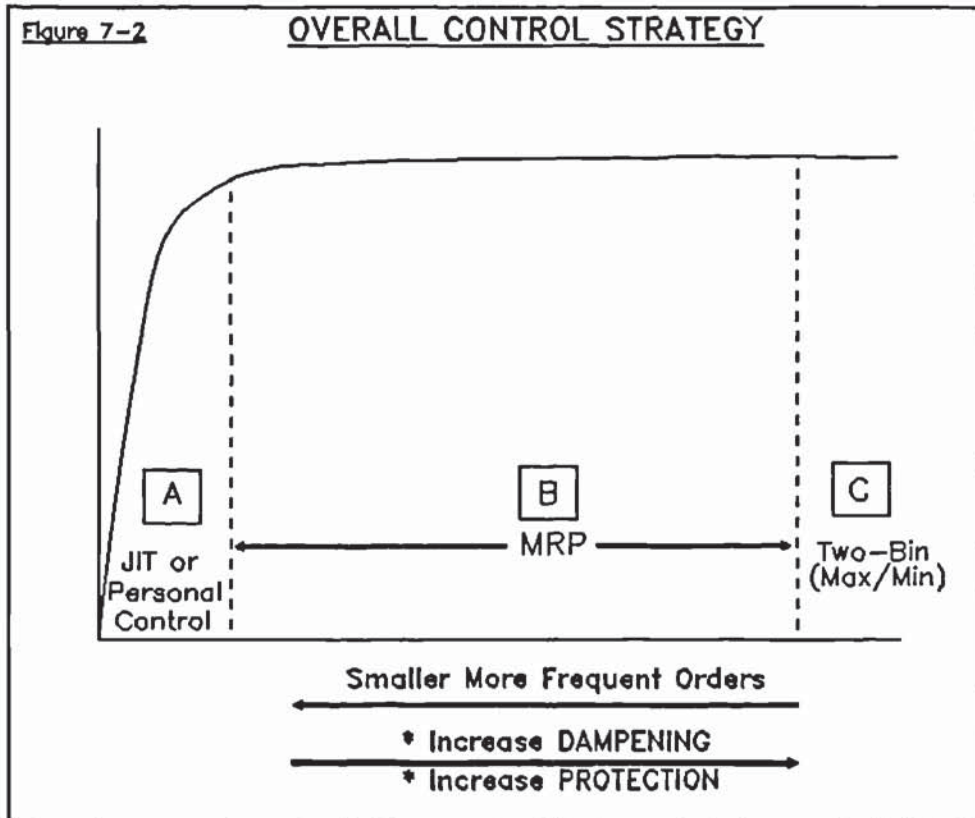
This is a tall order in view of all the conflicting objectives and failures of all the previous solutions and approaches. The remainder of this chapter discusses the general strategy to achieve MRP stability and enhance JIT purchasing to reduce operational costs.

7.8 The Strategy

The strategy operates within an overall framework of a long-term JIT program with the goal of reducing costs. The aim is to integrate JIT/Kanban, MRP, and Two-Bin systems as shown in Figure 7.2.

7.8.1 Two-Bin System

Typically the 'C' class items (which are the very low annual usage value items) should be introduced to the Two-Bin (Max/Min) system. This category of components are often the so called 'bulk issue' or 'free issued' items which are normally issued to the lines on an 'as required' basis. They are generally not part of any kit issue process. Because of their low value they should be totally excluded from the MRP systems. The total inventory value of these items will be insignificant and removing them from MRP will reduce the total volume of recommendations and also greatly reduce administrative costs associated with these parts.



7.8.2 Personal Control and JIT Purchasing

One of the principle criteria for selecting items for JIT is obviously annual usage value (AUV). The 'A' items should fall into this category. However, other items can also be selected for JIT purchasing based on other item characteristics. For instance:

- high unit value
- high usage
- bulky items
- constrained items
- material logistics etc...

The advantages of pulling to need are obvious, but developing JIT supplies is a long and evolving process. The decision to implement JIT purchasing should be taken progressively in a stage-by-stage manner, depending on the current status of the purchasing system and its adaptability to the JIT concept. For example, at the initial stage, the decision might simply be to negotiate a long term contract and get smaller

but more frequent deliveries, but otherwise to operate within the traditional MRP framework.

JIT deliveries will reduce inventory holding, but it can compound the manufacturing costs unless appropriate steps are taken. For example, as discussed earlier, the cost of transport will increase unless the increased deliveries are balanced by a reduction in another part of the system. How to achieve this balance will be discussed later. Switching to own or contract carriers to control in-bound logistics can reduce the total transportation costs. Similarly, implementing EDI (Electronic Data Interchange) can reduce the cost of order management.

While JIT contracts are being negotiated, the 'A' class items should receive close personal control, i.e. the demand for such items should be monitored closely and the supply of such items should be managed tightly in line with the demand. This will generally entail working manually inside the MRP cycle because most MRP systems are run on a weekly cycle and in some cases monthly - as in the case of IBM.

Managing manually will obviously be time consuming. However, because the administrative burden of managing the 'C' items is removed then the time saved can be redeployed in managing the 'A's. Manually controlling a large number of items is not practical, but that is no reason for not doing it for just a few. As people get used to the idea, having tried it on only a few parts, it is much easier to extend the idea to more. There are three advantages of controlling the high annual usage value items manually initially:

1. Because their inventory value is high, an immediate reduction in inventory can be achieved from their tight control while a JIT program is initiated.
2. Because the value of the remaining parts is lower, the MRP system can be made less sensitive to changes i.e. more stable by applying appropriate dampening.
3. Finally, personal control can produce the same degree of flexibility and inventory benefit as that derived from the more formal purchasing contract. This is an important consideration for smaller companies not yet in a position to secure JIT purchasing contracts.

7.8.3 Intervention Free MRP

Intervention free means that the MRP recommendations should be accepted without any amendments. The advantage of such a design is that the time and energy saved can then be better utilized to manage the 'A' class items where the inventory savings are much more significant.

In the past, as discussed in chapter 3, a lack of an integrated control strategy and poor design of operating rules and parameters (ordering, rescheduling, and safety policy) have resulted in the MRP recommendations being questioned. In general, because users lack confidence in the MRP output, they tend to review the recommendations before executing them. Invariably users have to manually amend the orders and rescheduling recommendations for a variety of reasons. For instance, poor rescheduling rules or parameters may cause the system to recommend a low value order to be rescheduled out, when in practice it may be prudent not to do so, or an order is recommended for expediting when sufficient safety stocks exist.

To achieve an intervention free system the rules should be consistent with business logic (i.e. Pareto principle - as discussed in chapter 2); the rescheduling rules should be such that they allow reschedules of the high value orders but suppress the low value ones as shown in Figure 7.2. Also to help reduce inventory without increasing the total order base, the ordering parameters should be such that it places smaller but more frequent orders for the high annual usage parts. The increase in the number of orders for the high value parts can be compensated by placing larger less frequent orders for the low value items. The actual ordering and rescheduling methodologies to achieve these effects are discussed next.

7.8.3.1 Ordering Methodology

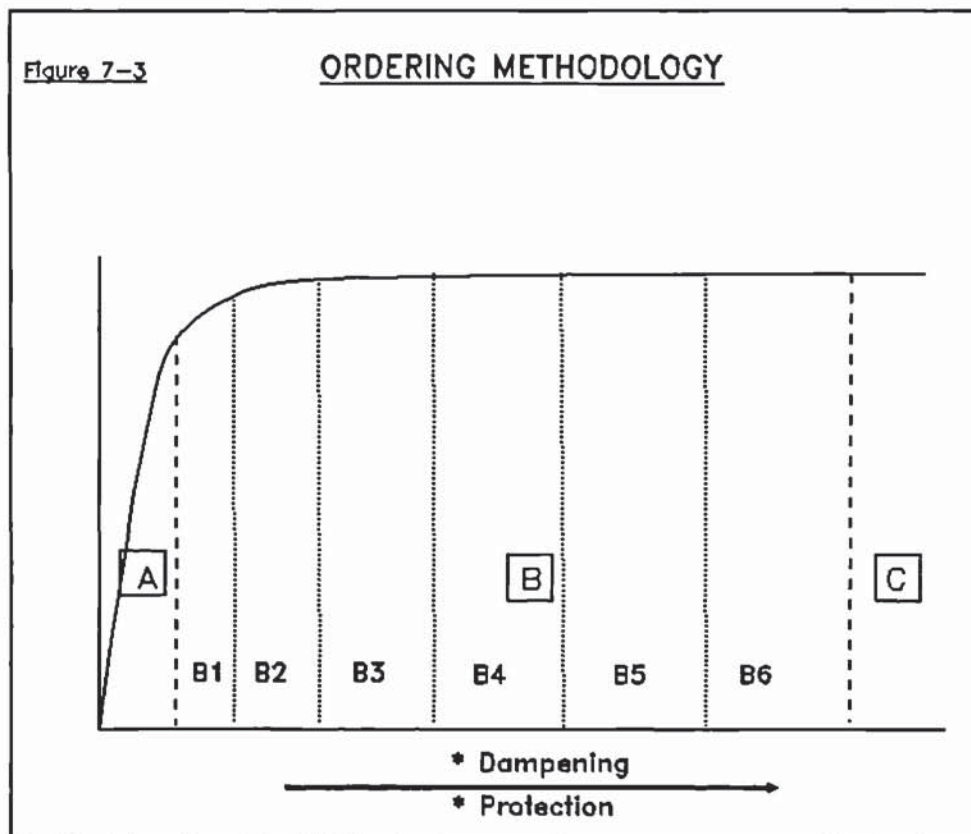
The ordering methodology has two aims: Firstly to reduce inventory; and secondly to achieve a regular delivery pattern. A regular delivery pattern is one of the features of the JIT delivery concept.

Figure 7.3 shows the principle of the ordering methodology to achieve both of these

objectives. The principle is to sub-divide the MRP controlled items into further groups, say B1, B2, B3, B4, B5, B6 etc. and to order each group of parts on a common ordering cycle according to the Pareto principle. In fact the grouping approach is compatible with the 'periodic order quantity' (POQ) rule. As discussed in chapter 5, this rule is the most widely used in practice. This is fortunate because it serves all the strategic requirements:

- a. it is simple to use
- b. it generates a regular schedule
- c. it is compatible with the ABC principle

However, as discussed in chapter 5, there are no clear guidelines to set the parameters for this rule in practice, i.e. how many groups should be used, what are the order cycles to use, and what are the group boundaries. Secondly, one wants to be able to predict the inventory levels and volumes of order recommendations that will be generated under a set of parameters before implementing them. The method to determine the ordering parameters and predict the MRP performance is developed in the next chapter.



7.8.3.2 Rescheduling Methodology

Initially, one would expect to reduce inventory without an increase in the total number of new order recommendations until an optimum or critical limit is reached. However, ultimately, to reduce inventory further would mean increasing the total number of orders. Increasing the number of orders in the system will thus perpetuate system nervousness. For business efficiency, a balance must be achieved between reducing inventory and minimising the cost of the additional order management. Clearly, the order workload can be reduced by dampening reschedule notices; but dampening means adding inventory - to dampen reschedule-ins, the protection must be increased to prevent potential shortages. Dampening reschedule-outs means inventory will come in earlier than required thus increasing inventory also.

Therefore for a successful process, the requirements of the rescheduling methodology are:

- a, reduce the number of reschedules
- b, reduce the total inventory investment

The conflicting objective of reducing inventory and order management costs can be achieved by applying calculated dampening. The principle is shown in Figure 7.3. The principle is consistent with the Pareto principle, i.e, the level of dampening must be set according to the value of the Pareto groups. That is, the lower the value class groups then the higher the dampening. For instance, B3 will have a higher degree of dampening than B2, which in turn will have heavier dampening than B1. In effect, the principle makes the system more reactive at the high value end and less sensitive at the lower end. The actual method to set the parameters will be developed in chapter 10.

7.8.3.3 Appraisal of the Methodologies

Under the ordering and rescheduling principles described, the increases in the number of orders and reschedules in the higher class groups will be compensated by a reduction in the lower class groups. The inventory reductions achieved in the high class groups will be more than the increase in the lower classes thus resulting in a net

reduction.

An important advantage of these methodologies is that they enhance the intervention free process because the orders and reschedules are reflective of the importance of the part (importance in terms of the inventory usage value).

Recall from chapter 3 that one of the reasons suggested for MRP failures was the accuracy of inventory. It is often suggested that an accuracy of between 95 and 98 percent is required to succeed. The benefit under the proposed methodology is that the criticality of inventory accuracy becomes less. Small errors in inventory are not critical in the low value classes because they are ordered in large batches. There will be sufficient inventory on hand to cover immediate requirements. As stocks deplete, any significant discrepancy between the inventory records and the stock on hand will become apparent and remedial actions can be taken. However, in most cases emergency purchases will not be required because:

- a. it is more than likely that the next order will arrive before the stock is exhausted;
- b. there will be sufficient safety stock on hand.

Thus, under the methodology described it is only necessary to maintain accuracy for a relatively few items. For these few items an accuracy of 98 or even 100 percent can be maintained without generating excessive workload. This is not suggesting that accuracy is not to be maintained on the low value items - it simply means that the effort required to maintain it must be balanced against the costs since there will be sufficient stock on hand to meet immediate requirements.

7.8.3.4 Migration to JIT

Having designed such rules it will take some time for the buyers/analysers etc. to accept the recommendations without first reviewing them. Progressively, as the users gain confidence in the recommendations, more and more recommendations will be accepted without review. In line with the Pareto principle only the high usage value orders/parts should be reviewed. As the process becomes more intervention free the resources freed up can then be used to migrate more parts to JIT/personal control.

The buyers can concentrate on vendor certification, purchasing contracts etc... rather than expending efforts reviewing MRP outputs for the low value items.

7.9 Comparison of Processes

The distinction between the traditional ABC classification and the above principle is that the former ABC groups were developed purely to set the ordering frequencies - the 'A's were ordered more frequently than the 'B's which in turn were ordered more frequently than the 'C's. These groupings were originally used in the reorder point (ROP) and later carried over into the MRP system. Groupings here, are created not for setting the ordering frequency but for operating different control systems i.e. JIT/MRP/Two-Bin. This is a significant difference and is the key to successfully control inventory and improve the MRP performance.

7.10 Defining Roles of MRP and JIT

Traditionally, MRP is implemented to control all the items. As discussed in earlier chapters, this has resulted in a very complex but rather poor performing MRP system. No system can be designed to cope with all the dynamics and complexities of the real world. With products becoming even more complex and customers demanding shorter lead times it becomes even more difficult to control everything by MRP. Furthermore, modern competitive pressures will force rapid and continuous business change. For this reason it is essential to have systems which are simple to use and easy to modify as the business needs change.

In the context of this the buyers should control and manage the high value items because the inventory consequences are much more significant while the remaining majority (but of relatively low value) should be left to MRP control. The MRP system can be protected from the dynamics of the production system by using robust rescheduling rules and safety policies. The MRP system shoulders the majority of the workload at a negligible inventory cost. This enables the MRP system to be simplified, while people - the most flexible of "systems" are used to control a relatively few but very high annual usage value items in a dynamic production environment. Such a strategic integration between personal control and MRP control

will enable the MRP system to remain simple but very effective while people manage the complexities of the "important few" items.

7.11 Defining the Boundaries Between JIT/MRP/Two-Bin

There are no right or wrong rules as to where the JIT/MRP/ROP boundaries should be. The objective is to put as many of the high value items under JIT/personal control as possible and at the other extremes to put as many items under Two-Bin (simple Kanban) as possible. The number of items under MRP control should be decreasing continuously as it becomes more intervention free - as more resources become available more items can be reviewed and migrated to either JIT or Two-Bin systems. A theoretical optimum point between the systems is reached when the total production cost is a minimum. As discussed in chapter 2, the cost benefits of reducing inventories must be balanced against potential increases in transportation costs and the costs incurred in disrupting any production.

7.12 Summary

It was noted in chapter 2 that the ABC (Pareto) analysis was by far the most widely used system prior to MRP. It is a very effective system from a management point of view because it separates the "important few" from the "trivial many".

This principle is used to define the point of integration between JIT, MRP, and Two-Bin (or Kanban). Under this principle the important few are managed under JIT or personal control while at the other extreme, the very low annual usage value items such as nuts, bolts, washers, etc...are controlled using the two-bin approach. This will reduce the number of items to be controlled by MRP and consequently reduce the MRP system nervousness.

Chapter 8

Setting Ordering Parameters

8.1 Introduction

Ordering rules and parameters are central to inventory management in MRP. Inappropriate rules and parameters result in fluctuating levels of new order recommendations and consequently highly volatile levels of inventory.

In the previous chapter, an ordering methodology was described; and it was noted that the role of ordering rules and parameters is to reduce inventory and also to enable JIT implementation in a modern manufacturing environment. In this chapter a method is developed to set the ordering parameters to meet those goals. The method also extends into an iterative model to predict the performance of the various ordering parameters commonly found in different ordering rules.

8.2 Decisions in Inventory Management

In ordering 'bought-out' inventory, MRP users are faced with numerous decisions. For instance:

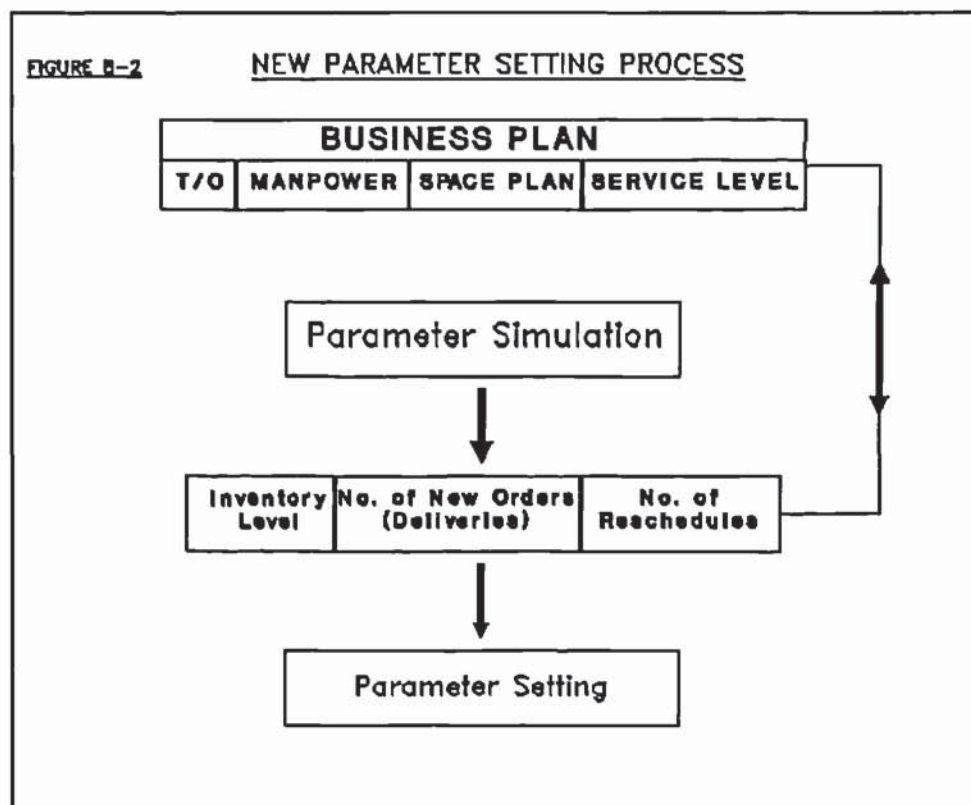
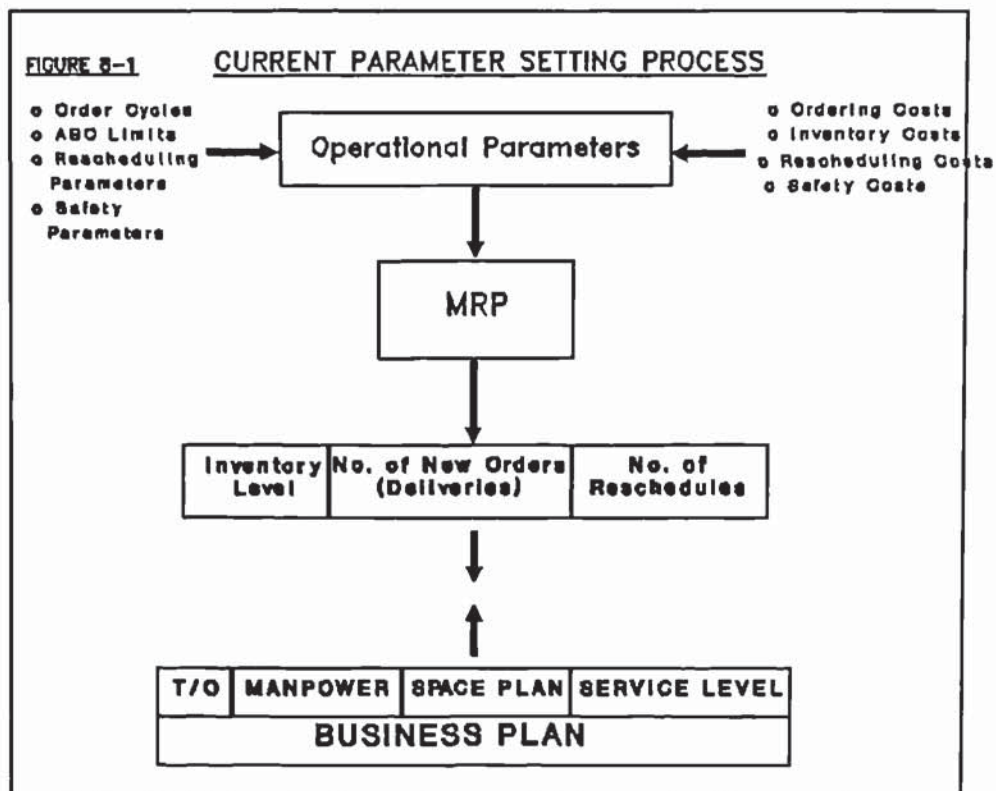
- a. Which ordering rule to use?
- b. What values to set for the various ordering parameters? (Such as ordering and receiving costs, inventory holding rate, ordering frequencies or order cycles, group sizes and number of groups).
- c. How will the parameters affect total plant inventory and order workload?
- d. More importantly, will the actual performance be in line with the inventory/business plan?
- e. Is the plan workable in the first place?
- f. Is there a better plan?

The choice of ordering rules affects the efficiency of the system whilst the values of the parameters affect lot sizes which in turn affect inventory levels and workload. Further, irrespective of the ordering rules used, it is difficult to estimate the total average plant inventory and order workload (macro performance) that will result when all the parts are considered together. This view is of prime importance to management for successful inventory planning and control.

8.3 Principles of The Model

Figure 8.1 shows the existing parameter setting process in IBM Havant. MRP ordering parameters are set and the MRP system is run for some time. The MRP output and the resulting inventory is compared with the business or inventory plan. If there is a difference, the parameters are changed. As discussed in chapter 4, this process of adjust and tinker is highly disruptive and inefficient.

The principle of the model is to reverse the whole decision making process. Instead of the parameters driving the business, the proposed model enables the prevailing business factors to drive the MRP system as shown in Figure 8.2. In words, the output from the iterative model is compared with the business plan. If the output is acceptable then the parameters producing the output are used as the parameter values for the MRP system.



8.4 Model For The POQ Rule

As noted in chapter 5.11, the Periodic Order Quantity (POQ) rule is the most frequently used in MRP. The model to define the optimum ordering parameters together with the method to determine the total inventory and number of order recommendations will be developed for this rule first. Later it will also be shown how the methodology can be extended to set and determine the outcomes of the complex EOQ based rules such as Least Total Cost (LTC) or Least Unit Cost (LUC) etc. noted in chapter 5.3.

Before developing the methodology for determining the optimum parameters and system performance under the POQ rule, it may be useful to review how this rule works and some of the problems encountered in practice.

8.4.1 Review of The Periodic Order Quantity Rule

The Periodic Order Quantity' (POQ) is the closest practical rule to true JIT ordering. It is also known by other names such as Periodic Batch Control, Fixed Days Cover, or Repetitive Ordering. The periodic order routine orders groups of parts on a regular order cycle (or frequency). It is a "weeks-of-supply" method and was discussed in chapter 5.3.

There are several advantages for grouping and ordering parts on a common order cycle. For example, it produces regular orders which simplify planning and consequently improve delivery performances, simplifies stock control, improves warehouse planning etc... There are many other reasons favouring this simple rule and are discussed by Aggarwal (1983).

In practice, the order cycles are obviously not specified for each individual item, but rather, they are set for a group of parts i.e. a common ordering cycle is set for the whole group. The grouping criterion and the common order cycles associated with each group are defined by the user. Typically, the grouping is based on the Pareto classifications. As was discussed in chapter 5, companies using this rule have no clear methods or guidelines to define:

- a. how many groups to use,
- b. how big should each group be,
- c. what should be the order cycle for each group.

All of these decisions affect the system and business performance. In one company visited, the groups were defined on the basis of the order workload per group. The reason was that each group was managed by a given buyer and hence an even spread of workload was required to balance the resources. Clearly, such an approach may balance the volume of order recommendations per buyer but totally ignores the impact of the decision on inventory and delivery costs or transportation costs.

Before developing the model it is worth clearing the distinction between a 'purchase order' and an 'order recommendation'. An order recommendation is a request for a delivery i.e. one order recommendation equals one delivery. Technically, the order recommendation should be called a delivery recommendation. On the other hand, a purchase order is a formal contract with the vendor and there is generally more than one order/delivery recommendation on a purchase order. The importance of this distinction is that whether traditional purchase orders or call-off purchasing schedules are employed, the number of delivery recommendations generated by MRP ordering parameters (assuming that they are not changed) will remain the same.

8.4.2 Model To Determine Optimum Parameters

Before determining the performance or behaviour of the system in terms of inventory and number of delivery recommendations, the process to set the optimum parameters required for the POQ rule is developed first. The actual method to determine the performance of the system is independent of the optimum parameter setting process.

For the POQ rule it is necessary to define the:

- a. class (group) limits which define the boundaries of the ABC groups,
- b. number of groups,
- c. common ordering cycles for each group of items.

The process to define the optimum parameters is based on a modified EOQ model. Although in chapter 5, the EOQ model was dismissed as being impractical, it is however, in theory correct. To make use of this model, the dependency on fixed costs must be eliminated. This is now developed.

8.4.2.1 Economic Order Cycles for Bought-Out items

MRP systems are time based, i.e. they are run on a regular interval such as weekly, fortnightly, or monthly. Therefore it is convenient to think in terms of order cycles or order frequencies, and order values or annual usage values (AUV) rather than the traditional order quantity as in the reorder point systems.

The EOQ formula in terms of the economic order cycle and annual usage value is:-

$$\boxed{\$D = (2.C/I) * (Y/f)^2} \quad \dots (8.1) \quad (\text{Refer to Appendix B})$$

Where

- \$D = Annual usage (spend) value (unit price * annual demand)
- C = Ordering + Receipt Cost
- I = Inventory carrying rate (as a decimal)
- Y = Number of working days in a standard company year
- f = Order cycle (in days)
- Y/f = Ordering frequency (No of orders per year)
- 2C/I = Cost ratio

The order cycle refers to how often an order is placed, i.e. an order cycle of 5 days means an order is placed every 5 days and therefore the ordering frequency would be 50 orders per year assuming there are 250 standard days in a production year.

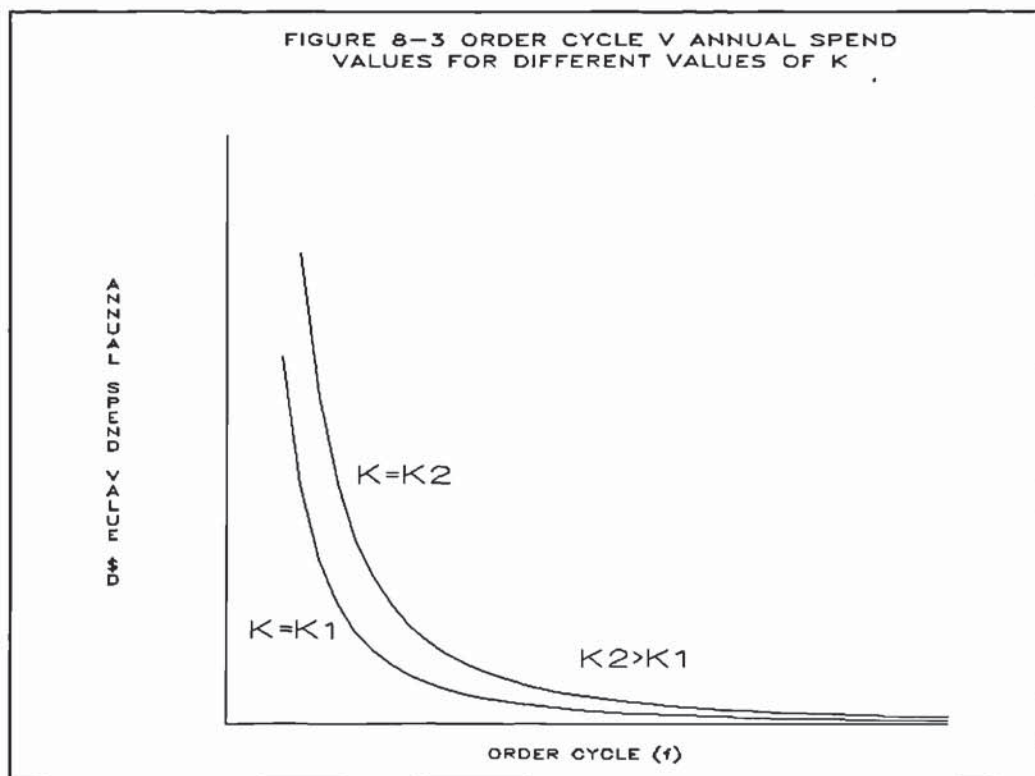
8.4.2.2 Eliminating The Use of Fixed Costs

The ordering cost and inventory carrying rate are always used as a ratio. Therefore for bought-out parts the cost ratio can be treated as a control variable (K), (refer to

Appendix B). Using the cost ratio of K eliminates the need to determine the order and inventory costs explicitly. Equation (8.1) can now be rewritten as :-

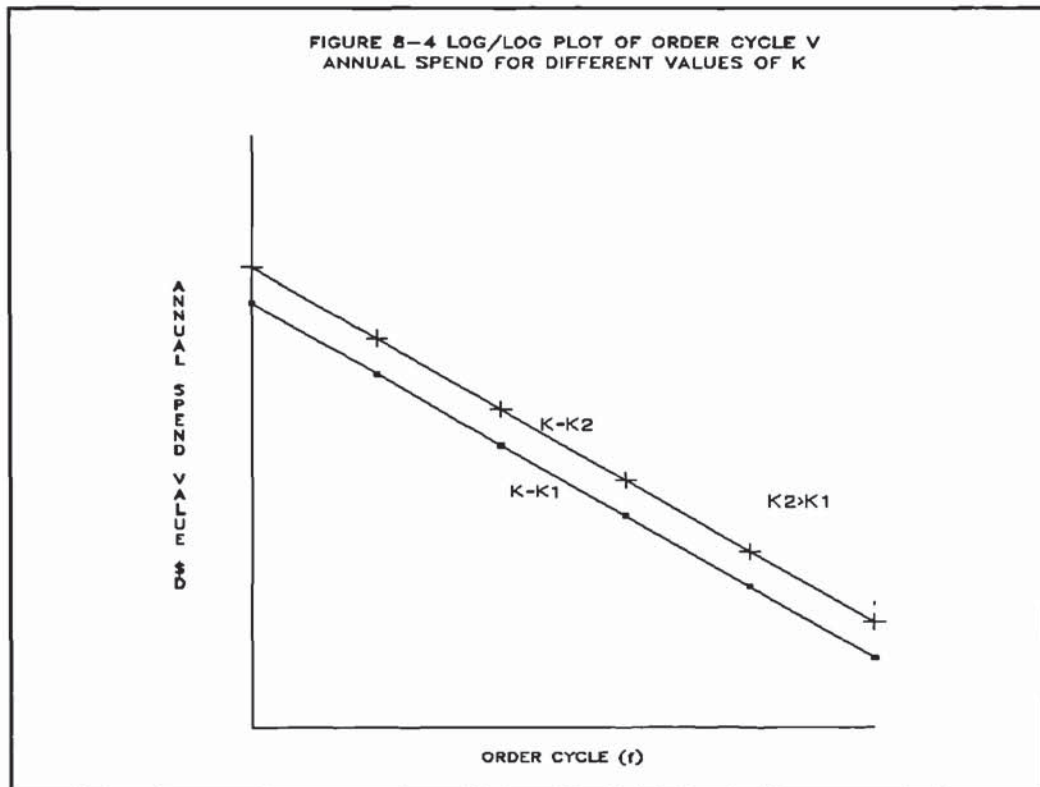
$$\boxed{\$D = (K) * (Y/f)^2} \quad \dots (8.2) \quad (\text{Refer to Appendix B})$$

This formula represents a decision rule for fixing the order cycle (or ordering frequency) for an item according to its annual spend value (or conversely determine the annual spend value for a given order cycle), where K is the controlling policy parameter. A particular value of K is applied to all parts. In practice, if the resulting order cycle for an individual item is inappropriate, for example, because of self-life problems, then this part would have to be dealt with be exception. This formula will be used to define the class limits and the optimum order cycles for groups of parts. Figure 8.3 shows the relationship between order cycle (f) and annual spend (\$D) for different values of K, i.e. K_1 and K_2 ($K_2 > K_1$).



Note from Figure 8.3, the high usage parts are ordered more frequently than the low usage ones. (Ordering frequency is the inverse of order cycle).

The same relationship plotted on a logarithmic scale is a straight line as shown in Figure 8.4 (Either natural or ordinary logs give the same results). Manipulation of this straight line requires only very basic mathematics and for this reason it is preferred to the original curve. The log/log graph will be used to demonstrate the method.



8.4.2.3 Procedure To Define Group or Class Boundaries

Group or Class boundaries or limits refer to the annual usage value (AUV) limits. They define the Pareto classes. Before defining the process two assumptions are made:

1. Assume that there are N items to be grouped into M groups (where M is much smaller than N) with the provision of a common order cycle for all the items in each group so as to minimise inventory for a given number of orders or vice-versa. If $M=N$ then the EOQ formula for each item renders the optimum solution. (Refer to Aggarwal, 1983). The items are grouped on the basis of the

annual usage value. The principle is shown in Figure 8.5

Figure 8.5 - Example of Item Classification		
<u>Pareto Position</u>	<u>Annual Spend Value</u>	
1	100,000	} Group (Value Class) 1
2	99,999	
3	99,998	
4	99,997	
5	99,996	
.	< ————— Class Limit
.	} Group (Value Class) 2
i	
i+1	
.	< ————— Class Limit
.	} Group M or Value Class M
.	
.	
.	
N-2	} Group M or Value Class M
N-1	2	
N	1	

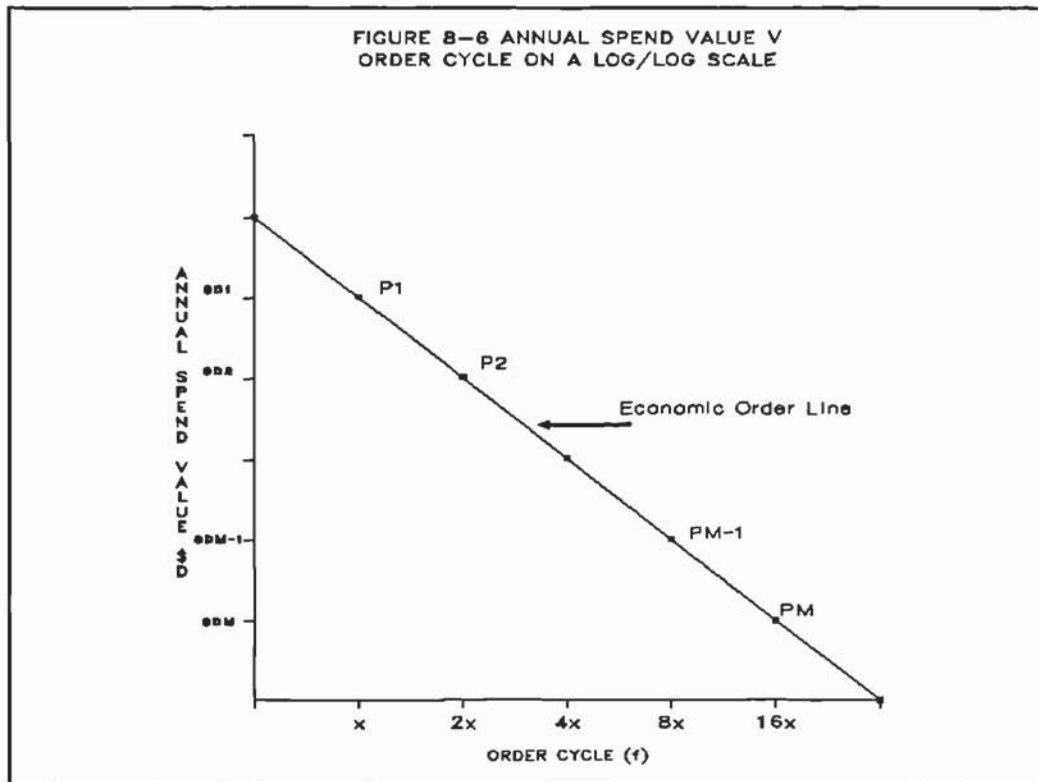
2. Aggarwal (1984) has shown that the relationship between the number of inventory items and their cumulative annual usage value is represented by a log-normal distribution (Pareto function) and for such a distribution the optimum order cycle for each successive group will follow a geometric progression such as $X, 2X, 4X, 8X$, etc. where X is the user defined initial order cycle. If a graph of order cycle against the annual usage value is plotted (shown later), the geometric relationship will become intuitively obvious. The geometric progression is a fortunate coincidence because it fits nicely with the practical order cycle pattern of weekly, fortnightly, monthly, bimonthly etc.

e.g. Group 1 - order cycle = 5 days (weekly),
 Group 2 - order cycle = 10 days (fortnightly),
 Group 3 - order cycle = 20 days (monthly) etc.

To explain the concepts involved, the procedure is demonstrated using a graphical approach. There are two steps involved in calculating the class limits. The first is to calculate the annual spend values for a given order cycle. (Later in section 9.4, it will be discussed why the order cycles are fixed and the annual usage value made the variable instead of vice-versa). The second step is to calculate the actual class limits or boundaries for a given number of classes or groups. The application of the method is demonstrated by way of a simple worked example later.

Step 1 Choose an initial number of groups and an order cycle pattern and calculate the corresponding annual spend value using equation (8.2). The method is iterative so any value of K can be used initially. Table 8.1 shows the general case for M number of groups with an initial value of $K=K_1$ and a common order cycle of X days for group 1 parts. Figure 8.6 shows the same results plotted on a log/log scale.

Table 8.1 - Order Cycle Calculations		
<u>Group or Class</u>	<u>Order Cycle (Given)</u>	<u>Annual Usage Value (Calculated)</u>
1	X	$\$D_1$
2	$2X$	$\$D_2$
3	$4X$	$\$D_3$
.
.
.
M-2	$2^{M-3}X$	$\$D_{M-2}$
M-1	$2^{M-2}X$	$\$D_{M-1}$
M	$2^{M-1}X$	$\$D_M$



Referring to Figure 8.6, point P_i corresponds to the order cycle and average annual usage value for class i , i.e. point $(X_i, \$D_i)$.

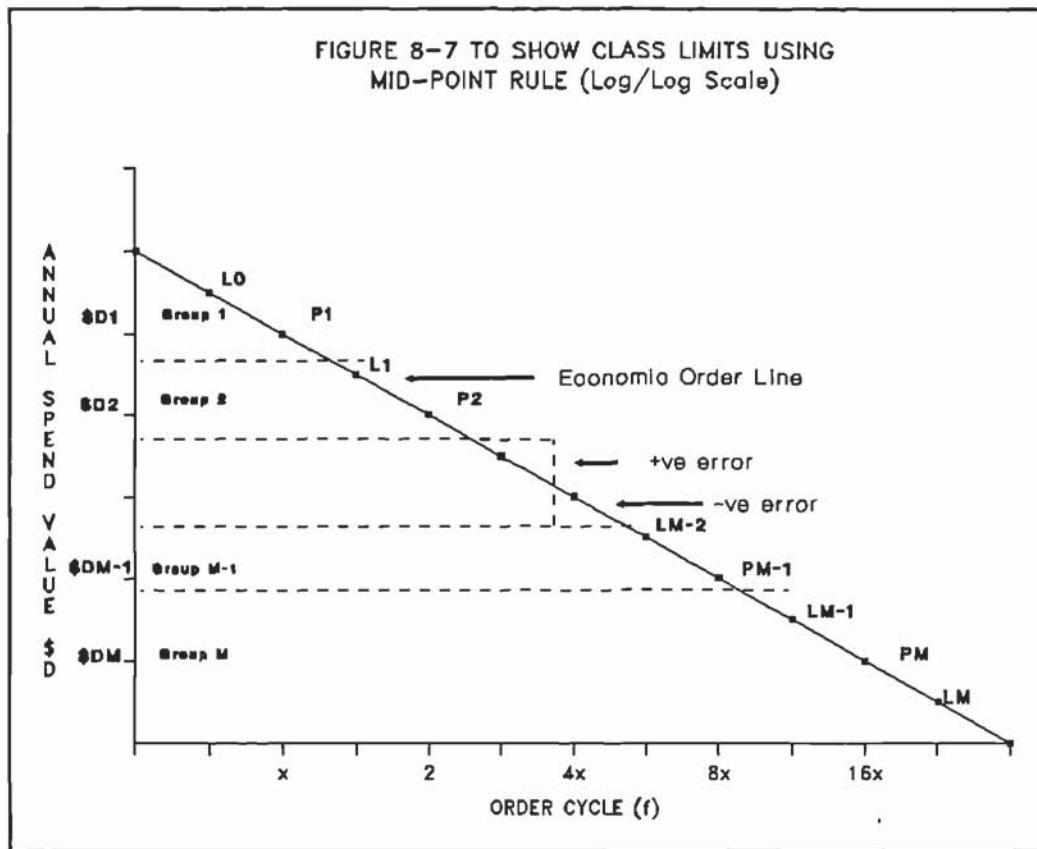
e.g. P_1 corresponds to the point for class 1 ($X, \$D_1$)

P_2 corresponds to the point for class 2 ($2X, \$D_2$) etc.

Step 2 In step 1 the economic order line is effectively calculated. This is fine if each item is uniquely ordered. However, the objective is to group a number of parts together and order them on a common order cycle. Therefore, the next stage is to now define the actual class limits to define the groupings.

To define the groupings, the net difference between the positive and the negative error (see Figure 8.7) must be a minimum. (This will be discussed in detail in section 9.5). The minimum point corresponds to the mid-point between two adjacent order cycles. Therefore this point is chosen as the class limit. Following this mid-point rule

gives the class limits.



Referring to Figure 8.7, L_i is the mid-point between P_i and P_{i+1}

e.g. L_1 is the mid-point between P_1 and P_2

L_2 is the mid-point between P_2 and P_3 etc.

For example, group 2 or class 2 parts are defined as those parts having annual spend value between L_1 and L_2 , group 3 parts are those between L_2 and L_3 etc... The actual annual usage value limits are given by anti-logging these values. In mathematical terminology, the class limits for each class are as shown in Table 8.2 below:

Table 8.2 - Class Limits in Mathematical Terminology

<u>Class</u>	<u>Upper Limit</u>	<u>Lower Limit</u>
1	Infinity **	$\geq L_1$
2	$< L_1$	$\geq L_2$
3	$< L_2$	$\geq L_3$
.	.	.
.	.	.
i-1	.	.
i	$< L_{i-1}$	$\geq L_i$
i+1	$< L_i$	$\geq L_{i+1}$
.	.	.
.	.	.
M-2	.	.
M-1	L_{M-2}	$\geq L_{M-1}$
M	L_{M-1}	0^{**}

** - These are the boundary conditions for the very top and the very bottom limits

8.4.2.4 Mathematical Procedure to Calculate Class Limits

The graphical process is shown to demonstrate the principle more visually. In practice the method is easily set up as a simple spreadsheet or as a database program. Table 8.3 shows a general spreadsheet for M groups. This should be modified to the number of groups actually required. (See worked example 8.2).

Table 8.3 - An Example of a Spreadsheet for M Groups

<u>Group or Class</u>	<u>Col1 Order Cycle</u>	<u>Col2 Annual Spend Value</u>	<u>Col3 Log(Col2)</u>	<u>Col4 Mid-Point From Col3</u>	<u>Col5 Antilog of Col4</u>
1	f_1	$\$D_1$	Y_1	$Y_1 - (Y_1 - Y_2)/2$	
2	f_2	$\$D_2$	Y_2	$Y_2 - (Y_2 - Y_3)/2$	
3	f_3	$\$D_3$	Y_3	$Y_3 - (Y_3 - Y_4)/2$	
.	
.	
.	
M-2	f_{M-2}	$\$D_{M-2}$	Y_{M-2}	...	
M-1	f_{M-1}	$\$D_{M-1}$	Y_{M-1}	$Y_{M-1} - (Y_{M-1} - Y_M)/2$	
M	f_M	$\$D_M$	Y_M	00	

Where

M = No of classes

f_i = Common order cycle for class i

$\$D_i$ = annual spend value corresponding to order cycle f_i

Y_i = log of $\$D_i$

Col1 - Common order cycle for each class (user defined)

Col2 - Corresponding annual usage value from equation (8.2),
for a given value of K, where K is defined by the user

Col3 - Log value of col2 (either log to base e or base 10)

Col4 - Mid-point between two successive values in Col3

Col5 - Antilog of Col4 (represent the actual class limits)
(Note that the lowest limit is always taken as 0).

Worked Example 8.2

Assume 6 classes are required and the order cycle for each class has the geometric progression 5,10,20,40,80 and 160 days as shown below. Taking $Y = 240$ days and an initial value of $K=100$, the table is:

<u>Class</u>	<u>Col1</u> <u>Order</u> <u>Cycle</u>	<u>Col2</u> <u>Annual Usage</u> <u>Value</u>	<u>Col3</u> <u>Log(Col2)</u>	<u>Col4</u> <u>Mid-Point</u> <u>From Col3</u>	<u>Col5</u> <u>Antilog</u> <u>Col4</u>
1	5	230,400	5.36248	5.06145	115,200
2	10	57,600	4.76039	4.45939	28,800
3	20	14,400	4.15833	3.85733	7,200
4	40	3,600	3.55627	3.25527	1,800
5	80	900	2.95421	2.65321	450
6	160	225	2.35218	0	0

Col 5 represents the class limits and they should be read as:

<u>Class</u>	<u>Upper Limit</u>	<u>Lower Limit</u>
1	< 999,999,999	> = 115,200
2	< 115,200	> = 28,800
3	< 28,800	> = 7,200
4	< 7,200	> = 1,800
5	< 1,800	> = 450
6	< 450	> = 0

Note - the upper limit for value class 1 is always effectively infinity and lower limit for the value class 6 is zero.

8.4.3 Procedure to Determine the System Performance

To calculate the total average number of order (delivery) recommendations expected and the average cycle inventory under a given parameter set; each item must first be assigned to the appropriate group depending on its annual usage value. Table 8.4 shows an example of items assigned to the appropriate value classes defined in worked example 8.2 above. This table will be used to demonstrate the method to determine the expected behaviour (macro performance) of the system under those parameters.

Table 8.4 - Assignment of Parts to Appropriate Groups

<u>Item No</u>	<u>Annual Spend Value</u>	<u>Assigned to Group</u>
1	900,000	1
2	190,000	1
3	170,000	1
4	150,000	1
5	130,000	1
6	90,000	2
7	70,000	2
8	50,000	2
9	30,000	2
10	24,000	3
11	22,000	3
12	20,000	3
13	13,000	3
14	9,000	3
15	7,000	4
16	5,000	4
17	4,000	4
18	1,500	5
19	1,000	5
20	100	6
21	75	6
22	50	6
23	25	6

8.4.3.1 Calculating Total Order Workload

The method to determine the total volume of new order recommendations generated over a year is broken into two steps.

Step I Determine the volume of orders generated by each group (value class) of parts. The standard equation to determine the average number of orders per part per year is:

$$\text{Average No of Orders per Part per Year} = \frac{\text{Days in the Year}}{\text{Order Cycle}}$$

The number of orders per group of parts is given by:

$$\frac{\text{Total No of Orders}}{\text{Per Group Per Year}} = \frac{\text{Average No of Orders Per Part} *}{\text{No of Parts in the Group}}$$

Using these two equations and the data from worked example 8.2 and Table 8.4:

<u>Class</u>	<u>Average No of Orders per Part per Year</u>	<u>No of Parts in Each Group</u>	<u>Total Average No of Order per Group</u>
1	240/5 = 48	5	48 * 5 = 240
2	240/10 = 24	4	24 * 4 = 96
3	240/20 = 12	5	12 * 5 = 60
4	240/40 = 6	3	6 * 3 = 18
5	240/80 = 3	2	3 * 2 = 6
6	240/160 = 1.5	4	1.5 * 4 = 6

Step II Determine the total volume of orders generated by the system.

$$\text{Total Orders in the System} = \text{Sum of the Orders in Each Group}$$

For the example, total orders that will be generated by the system is equal to $240 + 96 + 60 + 18 + 6 + 6 = 426$ orders per annum.

8.4.3.2 Calculating Total Cycle Inventory

Inventory resulting from the order recommendations is termed cycle inventory. Again, the method to determine the average cycle inventory expected is broken into two steps.

Step I Determine the cycle inventory per group (value class) of parts. The standard equation to determine the average cycle inventory per part per order is:

Average Cycle Inventory Per Part	=	1 * Total Annual Spend Per Part
		<hr/>
	2	No of Orders Per Part

The average cycle inventory per group of parts is given by:

Average Inventory Per Group of Part	=	1 * Total Annual Spend Per Group
		<hr/>
	2	No of Orders in the Group
	=	1 * Total Annual Spend Per Group
		<hr/>
	2	Ordering Frequency of the Group

Where the total spend per class or group is:

Total Spend per Class = Sum of Spend per Item in that Class

Whilst this calculation of average inventory assumes continuous consumption, the fact that some items may be used up at the beginning of an order cycle and some items may be used towards the end, is likely to balance out over the large number of items in each group.

In the example, the total spend for class 1 = sum of spend for items 1 to 5 inclusive
i.e. 900,000 + 190,000 + 170,000 + 150,000 + 130,000 = 1540,000.

Similarly total spend for:

Class 2	=	240,000
Class 3	=	88,000
Class 4	=	16,000
Class 5	=	2,500
Class 6	=	250

Using the order cycles in example 8.2 and a standard year of 240 days gives the

ordering frequency of 48, 24, 12, 6, 3, 1.5 for value class 1 to 6 respectively. Therefore the average cycle inventory in each group in the example is:

$$\begin{aligned}
 \text{Class 1} &= 1/2 * 1,540,000/48 = 16,042 \\
 \text{Class 2} &= 1/2 * 240,000/24 = 5,000 \\
 \text{Class 3} &= 1/2 * 88,000/12 = 3,667 \\
 \text{Class 4} &= 1/2 * 16,000/6 = 1,333 \\
 \text{Class 5} &= 1/2 * 2,500/3 = 417 \\
 \text{Class 6} &= 1/2 * 250/1.5 = 83
 \end{aligned}$$

Step II Determine the total cycle inventory in the system.

$\text{Average Inventory in System} = \text{Sum of Inventory per Class}$
--

For the example, total average plant inventory is equal to
 $16,042 + 5,000 + 3,667 + 1,333 + 417 + 83 = 26,542$ pounds.

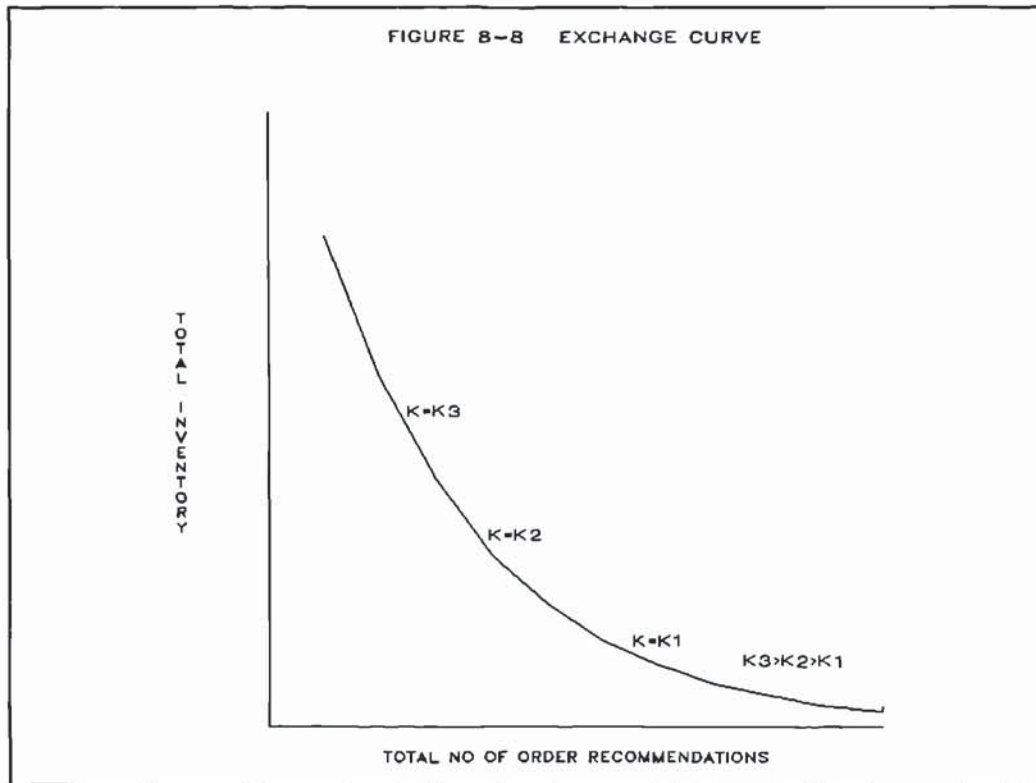
This inventory represent the average cycle inventory each MRP cycle.

8.4.4 Drawing the Exchange Curve

Having defined the procedure to determine the behaviour of the system under a set of parameters, the next logical step is to determine the performance under a different set of parameters. For example, keeping the order cycles the same, repeat the above calculation procedures (i.e. calculate the class limits and the corresponding total number of orders and total average cycle inventory) for another value of K. (Subsequently the above may be repeated for different order cycle progressions and number of classes). By repeating this process for several different sets of parameters the relationship between inventory and number of orders will be as shown in Figure 8.8.

This curve is commonly called an 'Exchange Curve' (see Corke -1987), since the inventory is exchanged for orders i.e. inventory can only be reduced at the expense of increasing the number of order (delivery) recommendations. For any selected value of K, the average number of orders and cycle inventory to be expected under the new

parameters can be compared with the existing parameters. The exchange curve represents the optimum balance between inventory and order workload for a given set of parameters.



Management is now in a position to choose a particular inventory/ordering scenario in its business planning (target setting) process. This model then provides the appropriate parameters for a given plan. Clearly, the procedure to determine the volume of orders and inventory is applicable to test the effects of existing parameters because it is only dependent on knowing the order cycles and class boundaries.

Before implementing any new policy, management should consider the following physical constraints which have not been taken into account.

1. The store may not be increased in size.
2. The purchasing or receiving departments may not be increased.

8.4.5 Operational Procedures Under The POQ Rule

1. Determine the No of classes and the order cycles to use.
2. Using an initial value of K, calculate the class limits.
3. From the database count the No of parts and sum the total annual spend value within each class.
4. Calculate the No of orders and inventory for each class.
5. Calculate the total No of orders and inventory in the system.
6. Repeat the calculations for another value of K
7. Draw the exchange curve and compare the difference between the existing policy and the proposed policy.
8. Once a suitable plan has been decided upon, select the appropriate parameters to input into the MRP system.

8.5 Model For The Complex EOQ Rules

Complex dynamic ordering rules are based on the EOQ models and were discussed in chapter 5. In brief, all of the EOQ based techniques balance the ordering costs with the inventory carrying costs. As discussed in chapter 5, these costs are obviously difficult to determine in practice. The methodology developed here overcomes these limitations by using a cost ratio. The cost ratio does not rely on absolute costs.

The model described previously was based around the Periodic Order Quantity rule. However, the method can easily be extended to approximate the complex EOQ based rules such as Least Total Cost and Least Unit Cost etc. discussed in chapter 5.3.

To use the method, all that is required is to convert the existing inventory holding rate and ordering cost into a cost ratio K. Once a K value is established, the standard equations for determining the inventory and number of orders can be used. Similarly, using the modified EOQ equation (equation 8.2), the behaviour of the system can be determined under different cost ratios. These two cases are explained in detail below.

8.5.1 Determining Level of Inventory and Orders

The standard equations for the number of orders and inventory per part are:

$$\text{Average No of Orders per Part per Year} = \frac{\text{Days in the Year}}{\text{Order Cycle}}$$

$$\text{Average Cycle Inventory Per Part} = \frac{1 * \text{Total Annual Spend Per Part}}{2 \text{ No of Orders Per Part}}$$

In order to use these two standard equations, the economic order cycle for the part number must first be determined. This is easily determined by rearranging equation 8.2 shown earlier.

$$\$D = (K) * (Y/f)^2 \quad \dots (8.2) \quad (\text{where } K=2C/I)$$

From which, the order cycle (f) is:

$$f = Y * \sqrt{(K/\$D)} \quad \dots (8.3)$$

Using the existing ordering cost and inventory holding rate, the cost ratio K can be determined. Having determined K, the economic order cycle for the an individual item and subsequently the number of orders and average inventory can be determined. Summing these for all the part numbers in the system will give the total volume of orders and the average cycle inventory.

Example 8.3 - Calculating the Level of Inventory and Order

Assume a part number ABC007 has an annual usage value of £250,000 and the current ordering cost is £10, the inventory holding rate is 20%, and the standard year is 250 days.

Then the cost ratio $K = 2 \times 10 / 0.20 = 100$

and the economic order cycle $(f) = 250 \times \sqrt{(100 / 250,000)} = 5$ days

Therefore the average number of orders per year expected for this part number $= 250 / 5 = 50$ orders

and the average inventory expected for this part number $= 1/2 \times 250,000 / 50 = £2,500$

Example 8.4 - A sample spreadsheet

The above process can easily be set up as a simple spreadsheet or a database from which the total volume of orders and inventory levels can be determined.

<u>Item No</u>	<u>Annual Spend</u>	<u>Col1</u> <u>EOQ Order</u> <u>Frequency</u>	<u>Col2</u> <u>No of Orders</u> <u>Expected</u>	<u>Col3</u> <u>Average</u> <u>Inventory</u>
1	900,000	96.0	96	4688
2	190,000	43.6	44	2179
3	170,000	41.4	41	2053
4	150,000	38.7	39	1938
5	130,000	36.4	36	1786
6	90,000	30.0	30	1500
7	70,000	26.4	26	1326
8	50,000	22.4	22	1116
9	30,000	17.4	17	862
10	24,342	15.6	16	780
			===	=====
			367	18228

Col1 - is the economic order frequency and is calculated using equation (8.3) above. In this example, K is taken as 100 and Y=240.

Col2 - is the expected number of orders under the above parameters.

Col3 - is the expected average inventory under the above parameters.

A point to note is that the actual number of orders and inventory may be slightly higher or lower for an individual part number than the one calculated using the above equations because most EOQ base rules in MRP systems round up orders. For instance, the Part Period Balancing rule will look ahead and look back to round up any small orders to minimise total costs over the planning horizon. In general, with several thousand part numbers in real MRP systems, the net effect should be minimum and therefore the rounding effects of the individual rules can be ignored.

8.5.2 Determining Optimum Cost Ratio

As noted earlier, the inventory holding and ordering costs are difficult to determine in practice. Under this method, such costs do not have to be determined explicitly. The behaviour of the system can be determined under different cost ratios. Then for the selected K (cost ratio), the ordering cost and the inventory holding rate can be expressed explicitly to input into the MRP system.

Example 8.5 - Determining the costs explicitly

Assume the accepted K value is 100. Then from $K=2C/I$, the costs can easily be stated explicitly. Notice, because the costs are always used as a ratio any permutation of ordering cost and holding rate can be chosen as long as the ratio remains constant.

For instance if $K = 100$, then $C/I = 50$.

From which C can be chosen as £5 and I as 10%, or C as £10 and I as 20% or any other permutations.

Generally, in practice the value of the inventory holding rate is assumed and fixed at an "arbitrary" level by management. In this case, only the ordering cost has to be determined. Arbitrary is used in double quotes because as discussed, the holding cost cannot be determined with any degree of certainty and therefore any value fixed is technically only a arbitrary value.

8.5.3 Operational Procedures Under The EOQ Based Rule

1. Determine the existing cost ratio.
2. Calculate the No of orders and inventory for each part number.
3. Calculate the total No of orders and inventory in the system.
4. Repeat the calculations for another value of K
5. Draw the exchange curve and compare the difference between the existing policy and the proposed policy.
6. Once a suitable plan has been decided upon, determine the appropriate ordering cost and inventory holding rate to input into the MRP system.

8.6 Advantages of The Model

The model enables management to evaluate whether a given inventory plan is feasible. Traditionally, it is assumed that the plan is workable and the system can be tuned to achieve that plan. As can be seen from Figure 8.8, there is a trade-off between inventory and workload and management must now decide what level of trade-off is acceptable under the prevailing business climate. Once that level is fixed, the parameters required can be selected from the model.

The model shows the overall relationship between inventory and order workload when all the parts in the system are considered together. It is based on marginal costing rather than the traditional absolute costs. That is, the model calculates the difference between the current and the proposed performance from which the user can determine whether the trade-off is cost effective.

Chapter 9

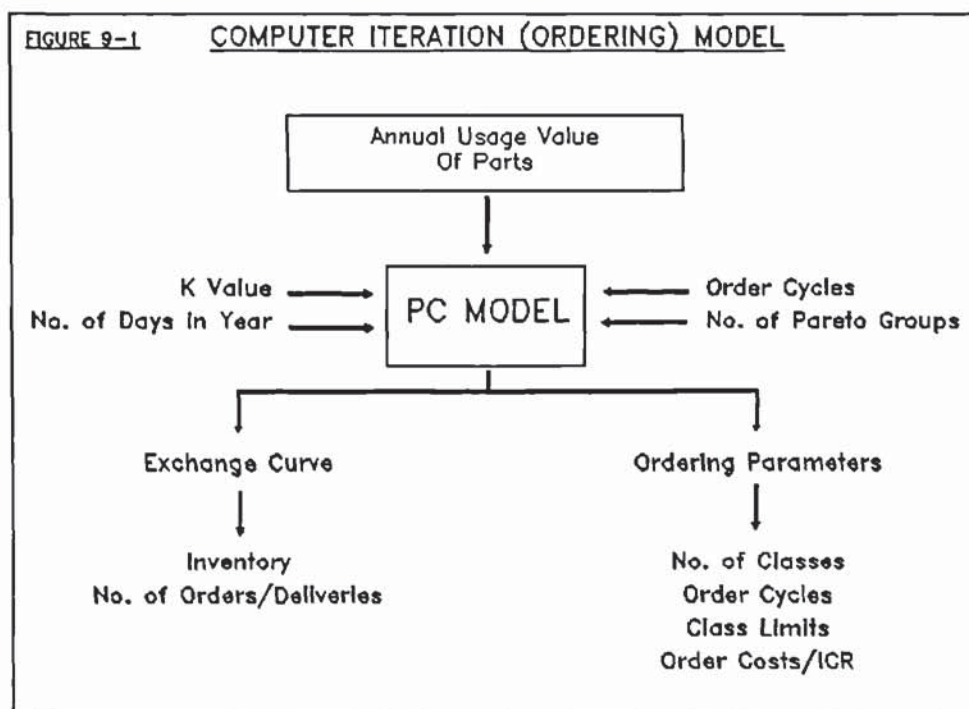
Assumptions and Characteristics of the Ordering Model

9.1 Introduction

In the previous chapter the ordering model was described without validating or justifying some of the assumptions used. In this chapter, the assumptions are discussed in more detail together with the characteristics of the model.

9.2 Iteration Model

Obviously, to manually walk through the whole procedure is a bit cumbersome especially when several thousand part numbers have to be considered in practice. Therefore the process described in the last chapter was developed as a computerised simulation model. Using this simulation model it was possible to determine the characteristics of the various ordering parameters acting in combination. Figure 9.1 shows the inputs and outputs of the computer simulation (ordering) model. Examples of typical output reports from the simulation model are attached as Appendix C.



9.3 Forecast of Annual Usage Value

To determine the annual usage value of a part number, it is not necessary to have the demand forecast for a whole year ahead because the EOQ curve is very flat near the optimum point i.e. the economic order point. For instance, a large demand forecast error will only result in a small deviation from the optimum point. For example, a 50 percent error in the demand forecast will result in a deviation of only about 8 percent from the true optimum position. A detailed discussion of the sensitivity of the EOQ rule can be found in O'Grady et al (1987).

In practice, the demand for a small future period can be factored to represent the average expected annual demand. The period chosen should be a typical period which reflects the average annual demand over the typical purchasing lead times. At IBM Havant, the average lead time for the bought-out parts is 3 months. The first order that the system will place today will be for a demand in month 4. Therefore the period chosen to determine the average annual demand is a six month period from month 4 to 9 inclusively as shown in Figure 9.2. The middle 6 months are chosen because they represent the typical expected demands at Havant.

Figure 9.2 - Average Annual Demand

Month :	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Demand:				X	X	X	X	X	X			

Total average annual demand for the part is the sum of the above demand multiplied by 2.

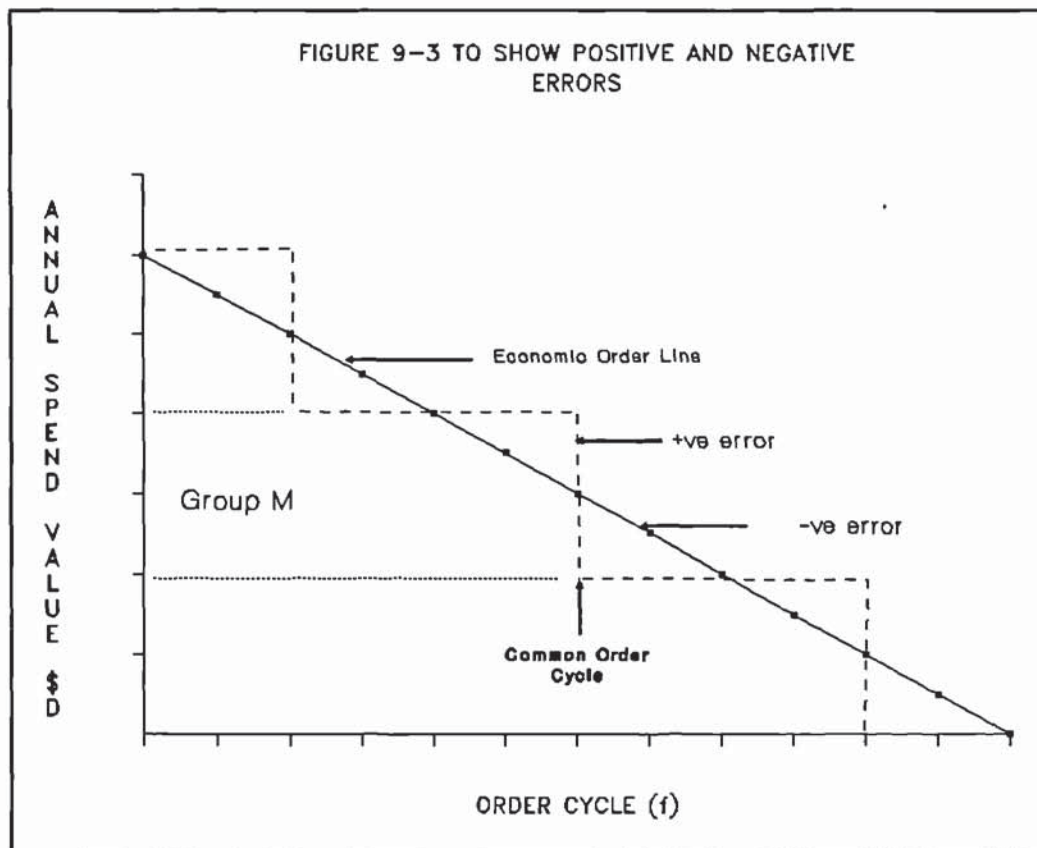
9.4 Fixing Order Cycles

The methodology described to determine the parameters is based around fixing the order cycles and then determining the annual usage values. Clearly from equation 8.2 the annual usage value could have been fixed and the corresponding order cycles calculated. However, the order cycles are fixed rather than the annual usage value because it is more desirable to control the delivery pattern rather than the order size.

A repetitive order cycle is more desirable because it is one of the features of JIT. As noted in chapter 7, the purpose of the ordering parameters is not just to control inventory but also to enable the business to progress towards or facilitate JIT delivery schedules.

9.5 Using The Mid-Point Rule To Set Class Limits

Equation 8.2 is a form of an exponential function and consequently forms a straight line on a logarithms scale. The mid-point rule is used to define the class boundaries on the logarithmic scale because the positive errors will cancel the negative error (see see Figure 9.3) when a large number of items are considered; as is the case in practical MRP systems where several thousand part numbers are involved. The error represent the deviation of the common order cycle from the economic order cycle.

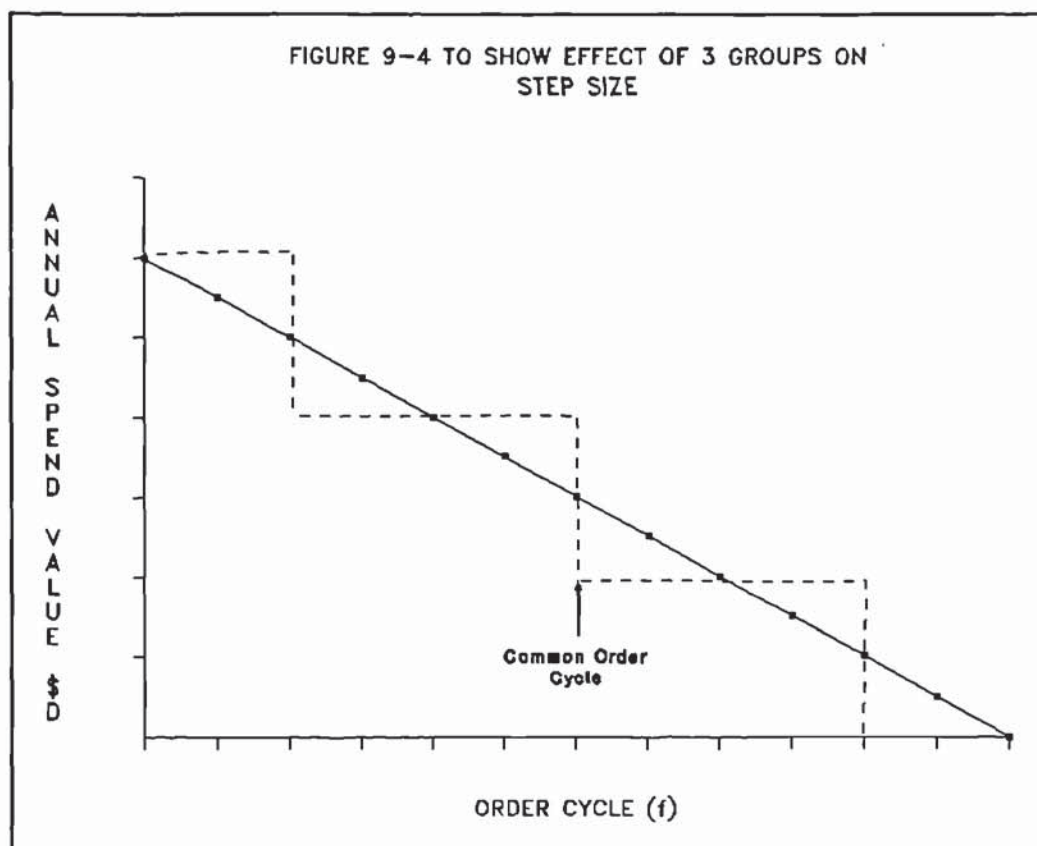


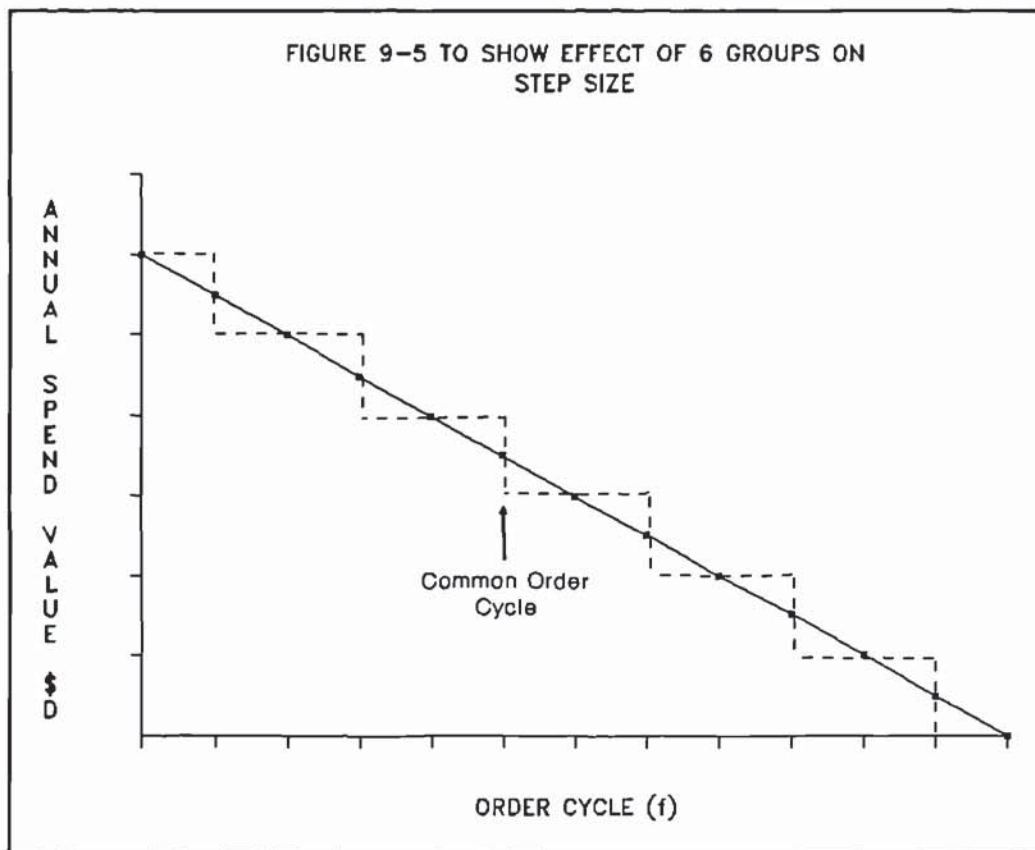
From Figure 9.3 it can be seen that parts falling to the right of the common order cycle for the group are ordered more frequently than their true optimum order cycle.

These parts will have the benefit of a lower level of inventory but at the penalty of increased number of orders. Conversely, parts falling to the left of the common order cycle will be ordered less frequently than the optimum order cycle and consequently will have the benefit of a lower number of orders but higher inventory.

9.6 Number of Groups

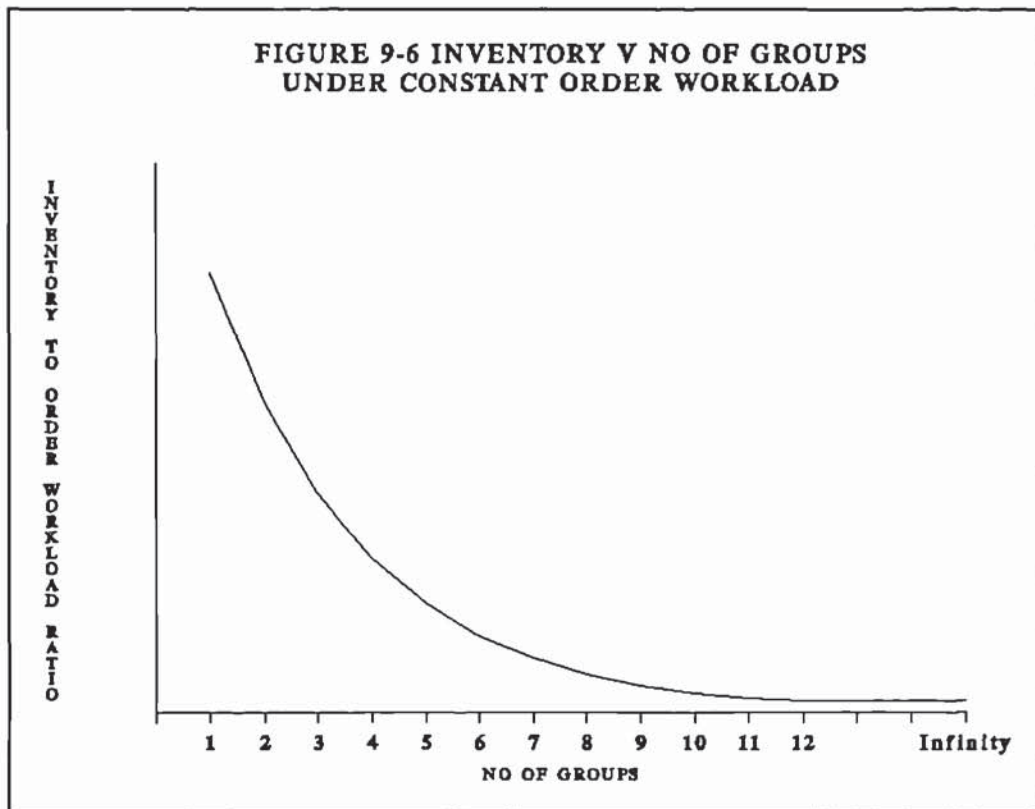
Effectively the class limits form a staircase running through the 'Economic Order' line. The size of the steps is determined by the number of groups. Figures 9.4 and 9.5 show the effect of using 3 and 6 groups on the step size. Increasing the number of groups (effectively reducing the step size), will reduce the deviation from the optimum line i.e. the EOQ line. Clearly, the minimum deviation occurs when the number of groups is equal to the number of parts, i.e each item is ordered separately. Further, if each item is ordered according to its economic order cycle then the deviation will be zero.





The fewer the number of groups then the larger will be the deviation of the performance from the true optimum. This was confirmed by simulations using real data from several companies and will be discussed later in section 9.9. It was also found that the inventory benefits depreciate exponentially as the number of groups increased. This is shown in Figure 9.6. From Figure 9.6 it is clear that the inventory reduction (for a given order workload) becomes negligible as the number of groups increase beyond 6. However, with less than 6 groups, there is a significant increase in inventory.

The practical significance of these findings is that there is considerable benefit in using more than the traditional 3 (ABC) groups but insignificant benefit in using more than 6 groups. (From a practical point, control becomes difficult if too many groups are used - 6 groups was found to be a manageable number at IBM).

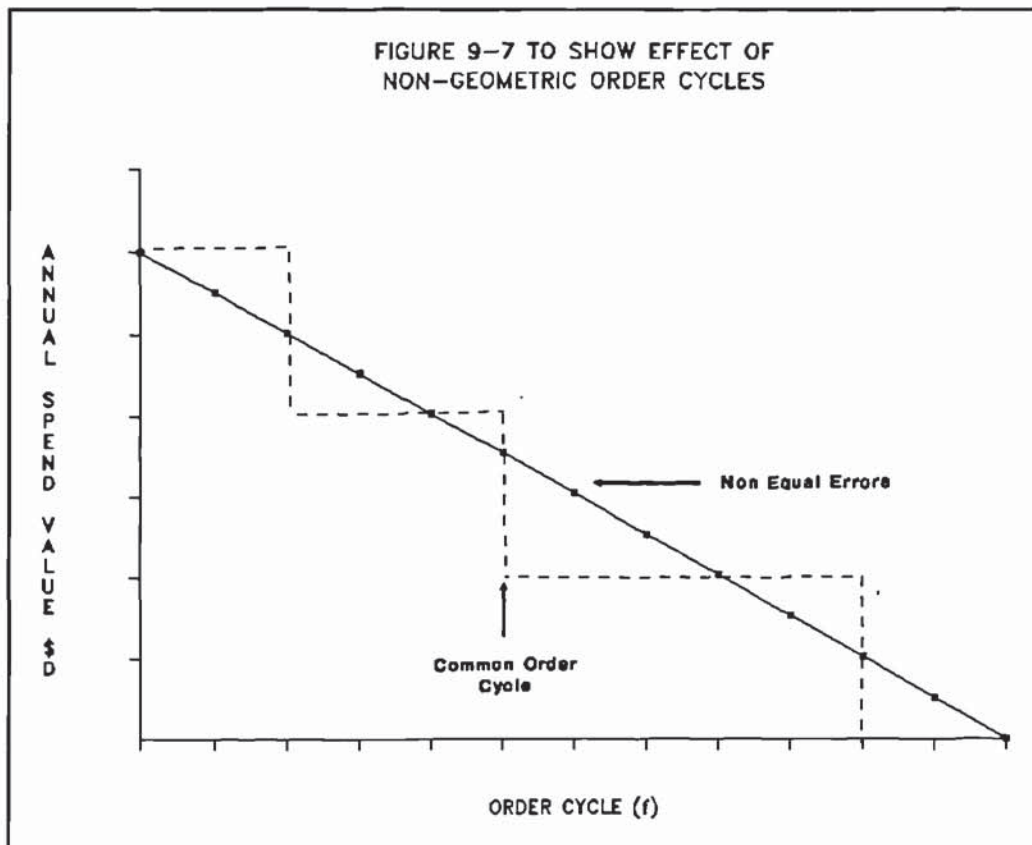


Another factor which will affect the size of the penalty (in terms of inventory level and number of orders) will be the steepness of the Pareto curve. However, from running a number of simulations using a range of Pareto distributions (from 70/30 to 90/10) from several different companies, it was found that the Pareto shapes had only a small effect on the size of the penalty. The main factor was the number of groups. Similar results were predicted by Crouch et al (1978) who have simulated the effect of the number of groups using several mathematical distributions.

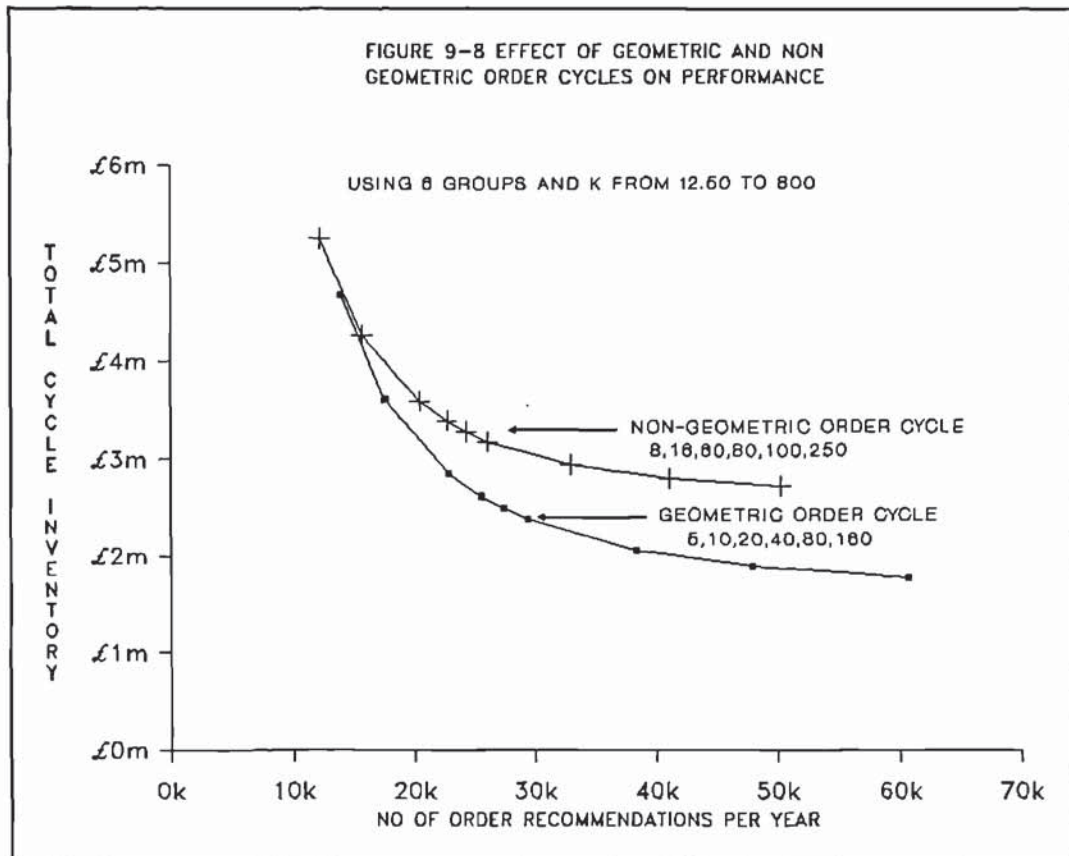
9.7 Geometric and Non-Geometric Order Cycles

With the proposed methodology of grouping parts, the value class boundaries are fixed by the order cycles. The use of the geometric order cycle progression generates groupings where the positive error is equal to the negative error. (As discussed in section 9.5, the error represent the deviation of the common order cycle from the economic order cycle). The advantage of such an approach is that the net difference between the errors is nullified.

On the other hand, non-equal errors are generated by using non-geometric order cycle progressions. (With the more traditional method used in practice, both the order cycles and class limits are set manually i.e. both are variable and therefore create non-equal errors). Figure 9.7 shows the effect of using non-geometric order cycle progression on the groupings.



The implications of using non-geometric order cycle progression are that the system performance (in terms of the inventory and number of orders) will be poorer than if a geometric order cycle progression is used. Figure 9.8 shows the system performance under 2 sets of order cycle progressions, one a geometric progression and the other a non-geometric one. Figure 9.8 shows the results of the simulations where 6 groups and various K values ranging from 12.50 to 800 were used. From this figure it is clear that there is a difference in the system performance.



From running a number of such simulations, it was found that this difference in performance ranged from almost 0 percent to over 50 percent depending on the number of groups, K value, and order cycle progressions being used. However, detailed analysis revealed that the impact of using non-optimum order cycles was relatively small compared to the other two factors. This is as might have been expected since the EOQ curve is very flat near the optimum point. The practical significance of this is that the user could use the order cycles which are most practical in their own particular environment without a serious deviation from the optimum curve.

9.8 Effects of Different Geometric Order Cycle Progressions

In the case of IBM, the most convenient order cycle progression was 5,10,20,40,80 and 240 days. However, the user should simulate to see the effect of different order cycle progressions (e.g. 1,2,4,8,... or 3,6,12,24... etc.) and compare the difference.

Figure 9.9 shows the effect of different order cycle progressions on inventory and orders. It is clear from the curves that as one moves more to the right, i.e. moves closer to daily delivery, then the number of deliveries rises rapidly without a significant inventory benefit. Implications of this are that a point will be reached in practice where the cost of transportation will outweigh the inventory benefit. This brings me back to the point made earlier in chapters 2 and 7 that JIT is not economical right across the plant. Therefore those implementing JIT supplies must carefully consider the cost of transportation in the total material logistic equation.

Another point to note from Figure 9.9 is that as one move further to the right, it becomes slightly more beneficial to progress towards daily delivery schedules, e.g. for the same number of total orders/deliveries, an order cycle progression of 1,2,4,8...provides a slightly lower level of inventory than say 3,6,12,24...

9.9 Performance Under Theoretical and The Modified EOQ Model

Clearly, any item that is not ordered according to its true economic order cycle will result in a non-optimum solution. The theoretical optimum is of course the diagonal line shown in earlier figures. The process to calculate the theoretical number of optimum orders and inventory for each part number is the same as the one described under the complex ordering rule in section 8.5 previously. Using the combined approaches to determine system behaviour, a comparison can be made between the true theoretical optimum and the grouping method. Figure 9.10 shows the system performance under the EOQ and grouping methodology. It is clear from the figure that there is a small penalty in using the grouping approach as opposed to ordering each item to its ideal order cycle. The actual size of the penalty is dependant on the number of groups, K value, and order cycles used. However, from detailed analysis of several simulations it was found that the penalty remained small for a wide range values in the above variables. The importance of this fact is that the grouped approach greatly simplifies the inventory control process without a significant penalty in inventory.

**FIGURE 9-9 EFFECT OF DIFFERENT ORDER
CYCLE PROGRESSIONS**

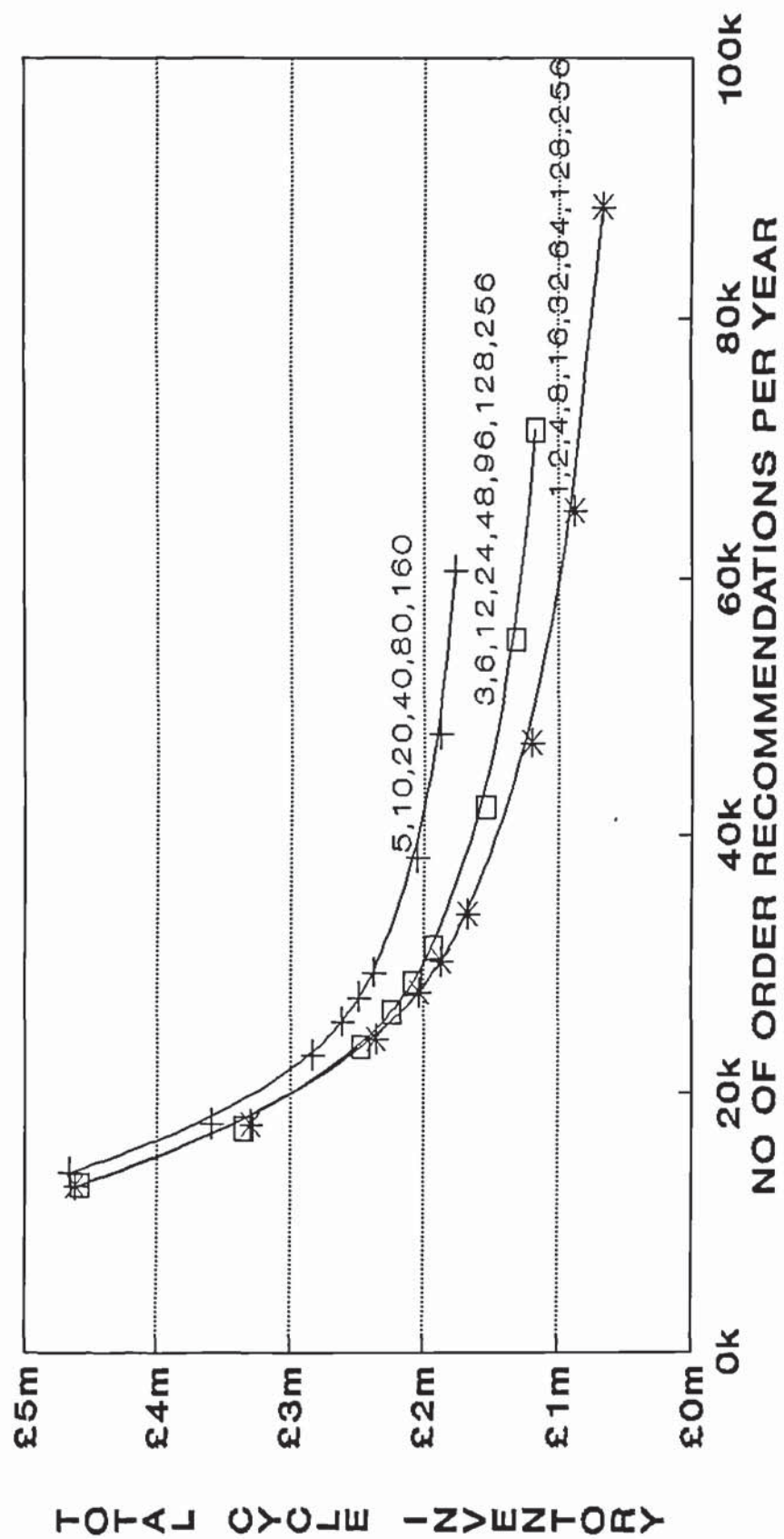
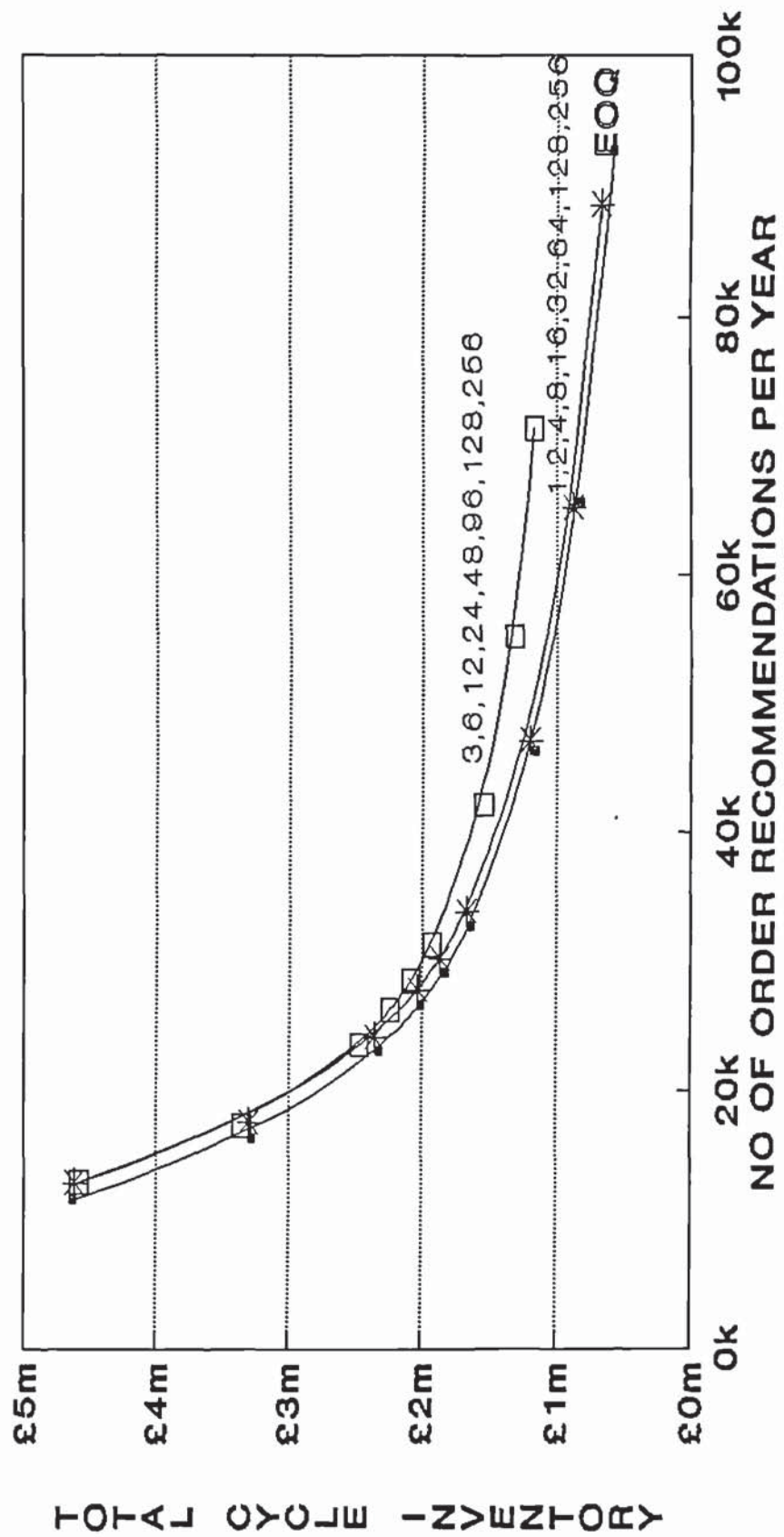


FIGURE 9-10 SYSTEM PERFORMANCE UNDER EOQ
AND GROUPING METHODOLOGY



9.10 Geometric Order Cycle progression

In the previous chapter, it was assumed that because of the log-normal relationship between cumulative annual usage value and the cumulative number of parts, the optimum order cycle progression would be a geometric one. This assumption is mathematically proven by Donaldson (1981) and later by Aggarwal (1983). However, this research took the opportunity to prove it empirically using the data from the IBM system.

9.10.1 Data Collection

IBM Havant used the 'Least Total Cost' (LTC) algorithm to order purchased items before the new method described earlier was implemented in 1989. The LTC rule is approximately the same as the traditional EOQ rule - see chapter 5. Prior to the implementation of the new method, data from each monthly MRP run was collected and analysed. In all, data for 525 part numbers (as shown in Table 9.1) was collected and analysed each month for a period of over a year.

Table 9.1: Example of Data Extracted

MRP Run No	Part Number	Annual Usage Value	Order No	Order Delivery Date
Jan 88	00000123456	120,000	P0001	5510
Jan 88	00000123456	120,000	P0002	5520
Jan 88	00000123456	120,000	P0003	5530
Jan 88	00000ABCDEF	90,000	Q0001	5510
Jan 88	00000ABCDEF	90,000	Q0002	5530
.....

N.B. - Order Delivery Date is in Shop Date.
 - Order is the MRP order recommendation.

9.10.2 Approach and Calculations

The 'days between orders' (DBO) were calculated for the orders generated by the 'LTC' rule. The difference between two consecutive order delivery dates for the same

part number (in the same run) gives the 'DBO' which is effectively the order cycle
- see Table 9.2.

Table 9.2: Example of the Calculations					
MRP Run No	Part Number	Annual Usage Value	Group No	Order Delivery Date	Days Between Orders
Jan 88	00000123456	120,000	1	5510	-
Jan 88	00000123456	120,000	1	5515	5
Jan 88	00000123456	120,000	1	5520	5
Jan 88	00000ABCDEF	90,000	2	5510	-
Jan 88	00000ABCDEF	90,000	2	5520	10
.....

The part numbers were then classified into six groups using a similar table as the one shown in worked example 8.2 in the previous chapter, but constructed with the actual ordering and holding costs used at Havant.

If the earlier assumption is correct then this approach should show that the majority of the DBO corresponds to the optimum order cycle for each group. The results are shown in Figures 9.11 to 9.14.

Figure 9.11— No of Days Between Orders
Group 1 Parts

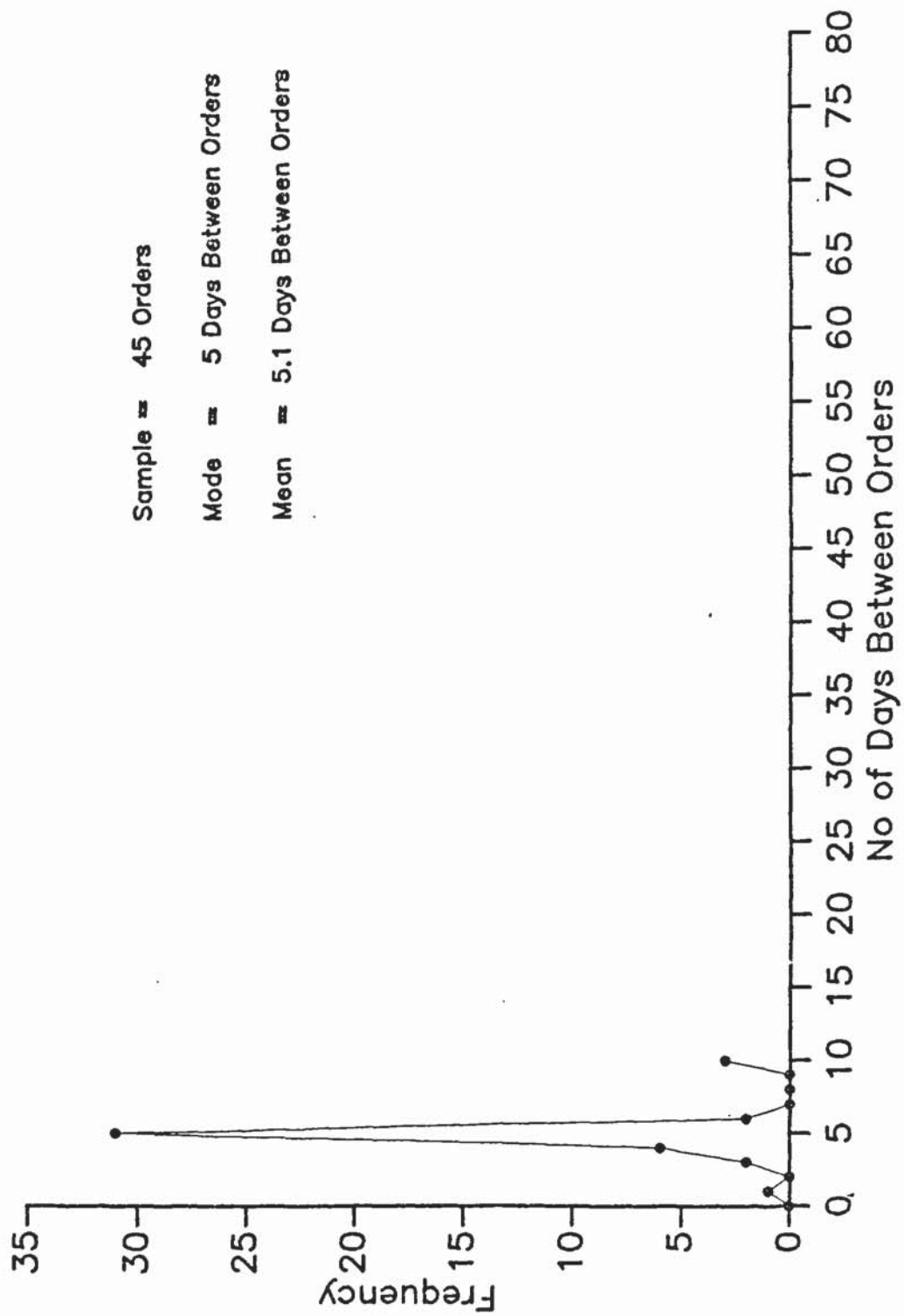


Figure 9.12— No of Days Between Orders
Group 2 Parts

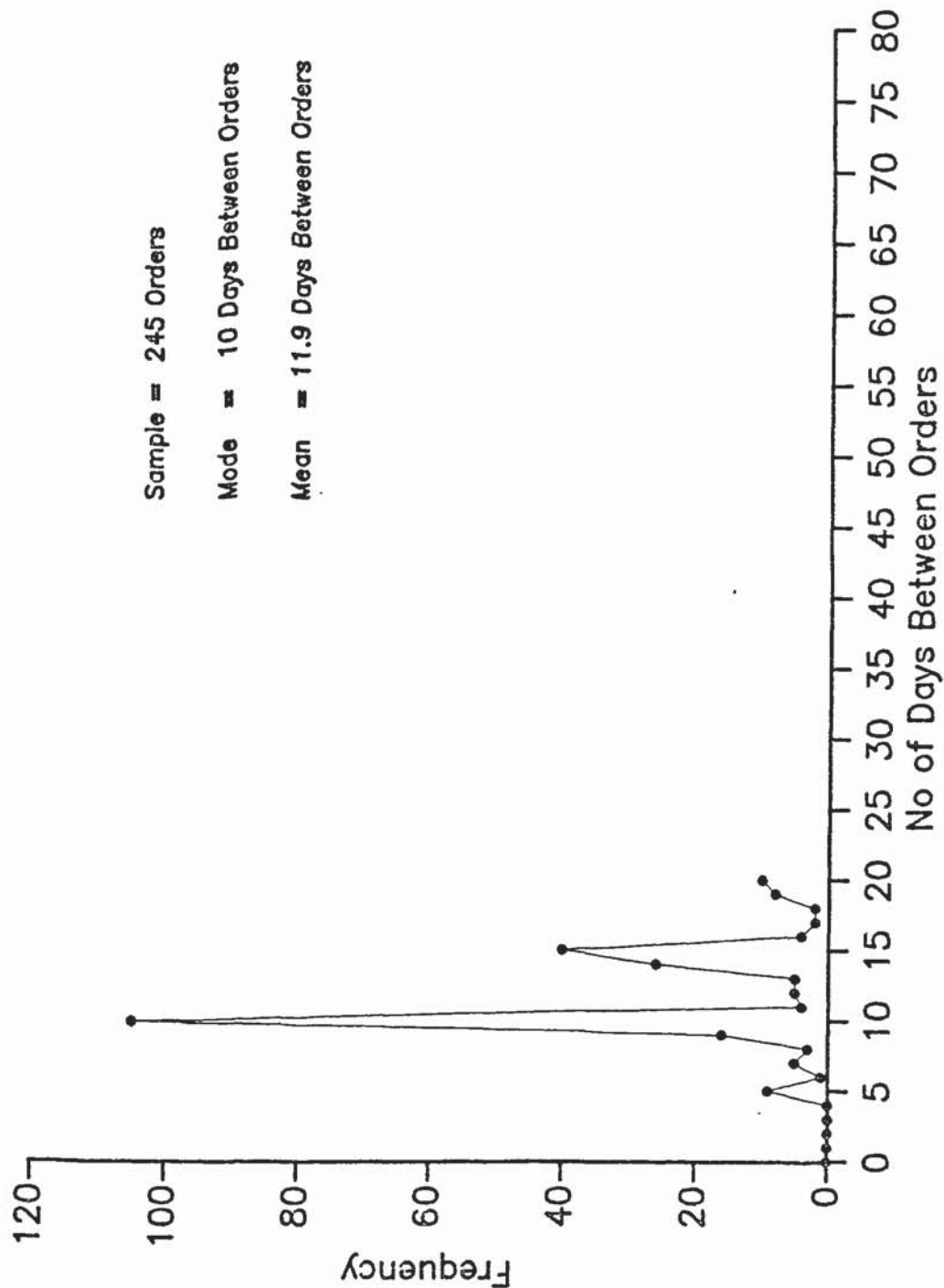


Figure 9.14— No of Days Between Orders
Group 3 Parts

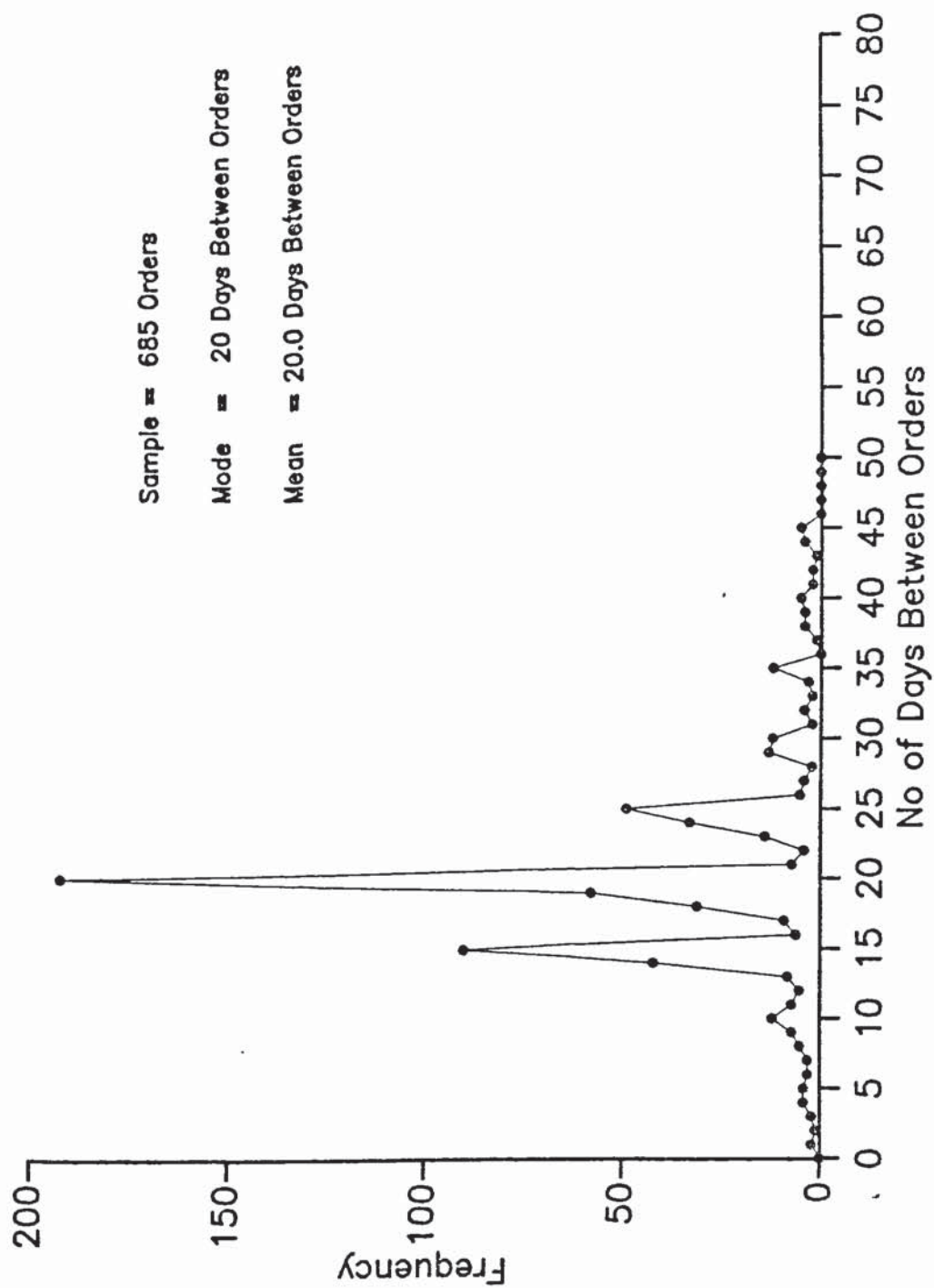
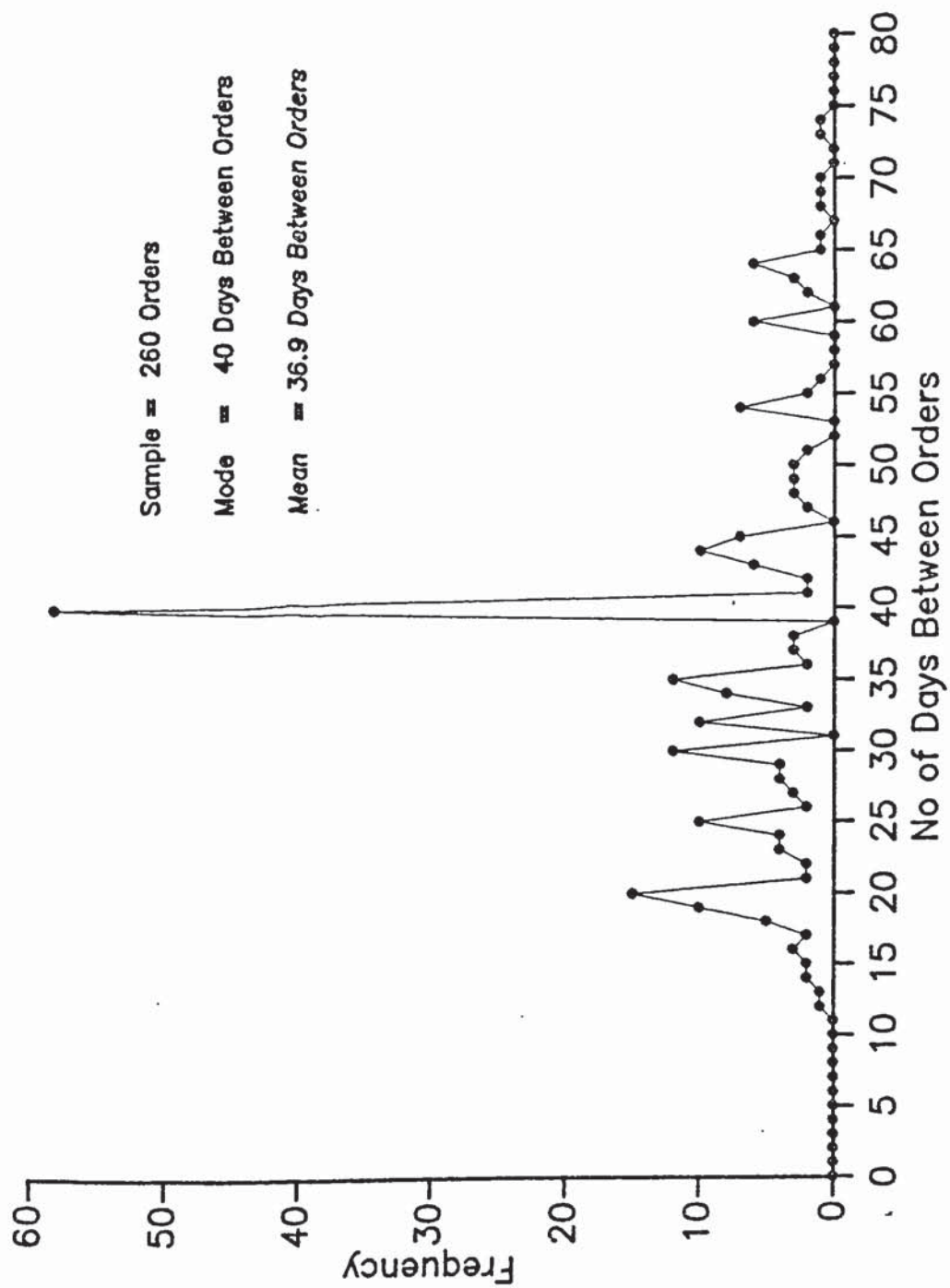


Figure 9.13— No of Days Between Orders
Group 4 Parts



9.10.3 Discussions of The Results

The peaks are generally at multiples of 5 day intervals - at IBM all the demands are grouped into weekly buckets - hence minimum days between orders should be a multiple of 5, except where there is a holiday.

The mode of each distribution does indeed correspond to the theoretical optimum order cycle. The mean of each distribution is quite close to the mode. Also in theory the range of DBO (or order cycles) for the:

- Group 1 items should range between 1 and 10 days
- Group 2 items should range between 5 and 20 days
- Group 3 items should range between 10 and 40 days
- Group 4 items should range between 20 and 80 days

However, there is an overlap of order cycles between the groups, whereas theoretically there should be none. For instance the actual DBO for the group 2 items range from 1 day to 20 days. The overlap occurs because the items were classified using the average demand in the middle six months, whereas the actual orders are generated by the actual demands in the front end i.e. if the items were classified using the actual orders generated rather than the average demand then there would be no overlap. However, this is not practical because the objective is to classify the parts before the MRP is run, not after the orders are already generated. There will be no overlap only if the average and the actual demand are exactly the same e.g.

Months:	01	02	03	04	05	06	07	08	09	10	11	12
Demand:	50	50	50	50	50	50	50	50	50	50	50	50
Average Demand = Actual demand per month												

If the actual demand is greater than the average then the 'days between orders' will be smaller than the one defined and vice-versa.

There were not sufficient orders to create a distribution for group 5 and 6 items. This is as would be expected - orders for group 5 item should on average have 80 days worth of demand and group 6 160 days...hence it will be rare to find more than one of two order recommendations per cycle for these items. (At least two order recommendations per item are required to calculate the 'days between orders').

9.10.4 Conclusion

From the results (Figures 9.11 to 9.14), it is clear that the optimum order cycle progression is indeed geometric in practice if the same parameters that are used to define the EOQ are used to define the group boundaries. The significance of this result is that the proposed method can be used to control the MRP system without a cost penalty. The advantage of the new method over the traditional EOQ based rules in MRP is that similar performance is achieved but without having to determine the ordering and holding costs - which are difficult to determine in practice.

This empirical proof was first published by the author in the International Journal of Operations & Production Management, Vol 11, 1991.

9.10 Comparison of The Techniques

The grouping technique developed through this research is an extension of the 'Coverage Analysis' work first done by Murdoch in 1965. Murdoch was one of the first to suggest the benefit of grouping parts together on the basis of their annual usage value. He showed that the optimum ordering frequency is proportional to the square root of the annual usage value. He used this relationship to group parts and order them on a common ordering frequency. However, to keep the calculations simple, he recommended that the group boundaries should be such that the square root of the mid-point between the boundaries should be a whole number. Using this assumption he then went on to define a table with 12 groups and the boundaries pre-defined by him. It is not clear how the boundaries are actually calculated, so the procedure cannot be used to define different series of boundaries. Using his pre-defined boundaries, he then calculated the common ordering frequency.

One of the limitations of his work besides not defining a procedure to determine the boundaries is that the ordering frequencies calculated by him do not follow a geometric progression. However, the major limitation of his method is that it was developed to review parts in the original reorder point systems. As was discussed in chapter 2, with MRP systems, parts are automatically reviewed each cycle. The important decision in MRP is therefore, not the review frequency but the ordering/delivering frequency. The latter point is what has been addressed in this research. The new method builds upon his ideas and the assumptions made by Donaldson to create a highly practical method suitable for MRP.

Before concluding this chapter, the contribution of others in developing the grouping approach - notably Crouch et al (1978) must be acknowledged. Crouch et al. proposed an iterative mathematical approach to defining the optimum group sizes based on dividing the range of demands of all items. Their criterion is that the division point will be the point when the total ordering and holding cost of one group is equal to the next group. The total cost of the whole system will be a minimum when all the groups are 'equi-costs'. In addition to the arguments levelled against cost previously, the main limitation of their work is that the number of iterations increase exponentially with the number of groups to such an extent that it is not practical. Others such as Chakravarty (1982) in recognition of the impracticality of Crouch's solution, have developed simplifying assumptions to limit the number of iterations. The main simplifying assumption is that the Pareto curve can be modeled as a log-normal distribution. With this assumption the mathematics become much simpler. However all the previous models have restrictive practical use because of their dependence on costs and in all these models both the order cycles and value class limits are variables. As discussed earlier in section 9.4, in MRP the order/delivery cycle are of prime importance and should be controlled by the user.

Chapter 10

Setting Rescheduling Parameters

10.1 Introduction

In chapter 7 it was suggested that to achieve an "intervention free" MRP system, the rescheduling rules should suppress trivial reschedules; trivial in the sense that small movements out of low value orders should be suppressed. Further, in chapter 8 it was noted that once the user reaches the exchange curve, further reductions in inventory are only possible by increasing the frequency of ordering/delivering and hence the volume of order recommendations. Consequently, increasing the number of order recommendations will increase system nervousness - clearly an undesirable side effect.

Well designed dampening rules and parameters are required to achieve a balance between a reduction in inventory and nervousness. Suppressing rescheduling-out notices will inevitably increase inventory because it is coming in earlier than required. On the other hand, freezing reschedule-in notices will increase the likelihood of shortages unless appropriate protection is applied to compensate for suppressing the order expedition.

This chapter develops the rescheduling method discussed in chapter 7 into practical models. There is a methodology/model for dampening reschedule-ins and another one for dampening reschedule-outs. These will enable the user to control the volume of reschedules and consequently the degree of system nervousness. It will also enable the user to target the dampening to achieve the maximum benefit.

10.2 A Recap of Problems in Rescheduling

In Chapter 2, it was noted that the volume of rescheduling notices is a major operational problem with MRP. Users have implemented a variety of rescheduling rules to reduce the volume of unnecessary reschedules; but the rules and parameters

are set without actually knowing their effect before hand. Before any rescheduling rules or parameters are implemented it is critical to know:

- a. how the rule will affect orders
- b. how many reschedule notices will be suppressed
- c. what will be the inventory impact

10.3 Requirements of the Rules

To reduce system nervousness is simple - simply increase the dampening. However, the requirements of the rules are not just to suppress movement. The rules must have a clear and simple logic so that the system recommendations can be easily followed. Also the rules must be such that they will enable the user to achieve an "intervention free" system. To achieve this goal, the rules must create recommendations which are consistent with business logic i.e Pareto principle, otherwise the analysts will manually alter the recommendations. In the remainder of the chapter, the models to set the rescheduling-out parameters and rescheduling-in parameters are discussed separately.

10.4 Reschedule-Out Dampening Model

In chapter 6 it was discussed that there are numerous dampening rules available in commercial MRP systems. Most of the rules are based on optimising the cost of rescheduling against the cost of holding inventory. Such costs are difficult to determine in practice and the rules are relatively complex yielding results which are not easily understood by the users - hence the frequent manual changes or intervention.

To achieve an intervention free process, the dampening rule developed through this research is directly related to the ordering rule described in chapter 8. It is based on value class and dampening days. The principle is that the higher the value class (thus value of the order) then the lower the dampening and vice-versa. A common dampening (in days) is applied per class, such as shown in Table 10.1.

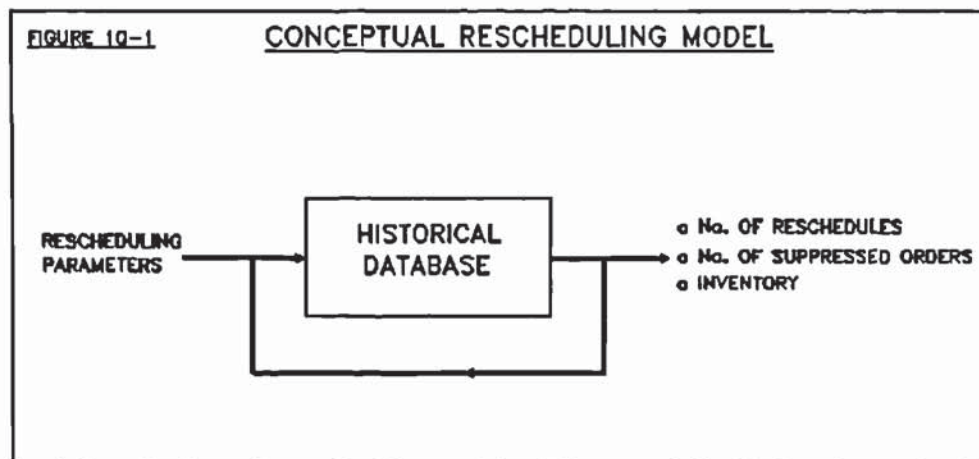
Table 10.1 - Example of the Dampening Principle

Value Class	Dampening
-----	-----
B1	0 Days
B2	5 Days
B3	10 Days
B4	20 Days
B5	40 Days
B6	80 Days

The disadvantage of suppressing any reschedule-out notices is that inventory will be higher than the minimum required. Of course, this is true with any rescheduling-out dampening rule. The advantage of this methodology is that the effect is minimised because heavier dampening is applied on the low value orders where a higher fraction of reschedules are reduced for a negligible increase in inventory.

10.4.1 Procedure for Determining Optimum Dampening Level

As mentioned earlier, before a rescheduling rule is implemented it is essential to understand its effect on reschedules and inventory. To estimate the reduction in the number of reschedule-outs and its effect on inventory it is necessary to monitor the existing reschedules in detail, i.e. order value and amount of movement suggested by the system should be stored as an historic database file. (An extract of such a database is shown in Appendix D). Using the historical database the expected level of dampening and impact on inventory under a new set of parameters can be investigated. Figure 10.1 shows the conceptual model. The procedure to determine the number of orders suppressed is as follows:



Step 1 The first step should be to define the number of classes and the class limits using the procedure described in chapter 8. Assume the parameters determined are as shown in Table 10.2.

<u>Value Class</u>	<u>Lower Class Limit</u>	<u>Order Cycles</u>
B1	210,000	5 Days
B2	52,000	10 Days
B3	13,000	20 Days
B4	3,000	40 Days
B5	800	80 Days
B6	0	160 Days

Step 2 Using the group boundaries, allocate the historical rescheduled items into appropriate groups as shown in Table 10.3. (The item's annual usage value will be required).

<u>Part No</u>	<u>Annual Usage Value</u>	<u>Value Class</u>
XYZ001	60,000	B2 from above
UVW002	53,455	B2 limits
MNO007	12,350	B4 etc..

Step 3 Define an initial set of dampening days. Assume the dampening is as shown in Table 10.1 earlier.

Step 4 Using the historical database simply calculate the difference between the new order due date and the old order due date. If the difference is greater than the proposed dampening then the order would have been rescheduled. If it is less than or equal to the proposed dampening then it would be suppressed. For example, the items shown in Table 10.4 fall within the B2 boundaries and the proposed suppression for this group of parts is 5 days.

Table 10.4 - To Show Difference in Due Dates

<u>Part No</u>	<u>Order No</u>	<u>Order Value</u>	<u>New Due Date</u>	<u>Old Due Date</u>	<u>Due Date Difference</u>	<u>Dampening Days</u>
XYZ001	00001	£2,500	5005	5000	5	5
XYZ001	00002	£2,800	5010	5003	8	5
XYZ001	00003	£2,300	5015	5012	3	5
UVW002	00004	£2,000	5010	5004	6	5

In this example, only order numbers 0002, and 0004 will be rescheduled under the proposed parameters. The remainder will be suppressed. Therefore, the reduction in number of reschedules will be 2. (Note: the due dates are in shop dates)

Step 5 As a result of not rescheduling, the resulting inventory will be excess. The average value of the excess inventory per cycle is given by summing the value of all the suppressed orders over the historical period and dividing by the number of MRP cycles in that period i.e:

<u>Part No</u>	<u>Order No</u>	<u>Order Value</u>
XYZ001	00001	£2,500
XYZ001	00003	£2,300
Total Excess Inventory Over the Year = £4,800		
Average Excess Inventory per cycle = £400 (assuming 12 MRP cycles in year)		

Step 6 Repeat steps 3 to 5 until the level of nervousness and excess inventory is acceptable. These should then be the value of dampening inputted into MRP.

10.4.2 Characteristics of The Rescheduling-Out Rule

Before a change in the existing rescheduling rule was permitted by management at IBM, it was necessary to investigate the effect of the proposed rule under different sets of parameters for two reasons:

- 1, to determine the appropriate dampening days
- 2, to demonstrate the credibility of the rule to management

To investigate and demonstrate the characteristics of this new rule, over twelve months' of IBM's historical data was used. The model was designed to investigate the three dimensional relationship depicted in Figure 10.2. Figure 10.3 shows the general relationship between excess inventory and the total volume of reschedule notices in the system. Figure 10.4 shows the general relationship between number of reschedules and dampening days for a given value class and Figure 10.5 shows the relationship between excess inventory and dampening days for a given value class.

FIGURE 10-2 RELATIONSHIP UNDER INVESTIGATION

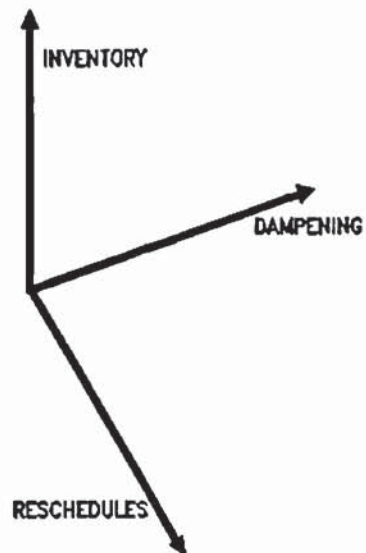


FIGURE 10-3 RELATIONSHIP BETWEEN INVENTORY and NUMBER OF RESCHEDULES

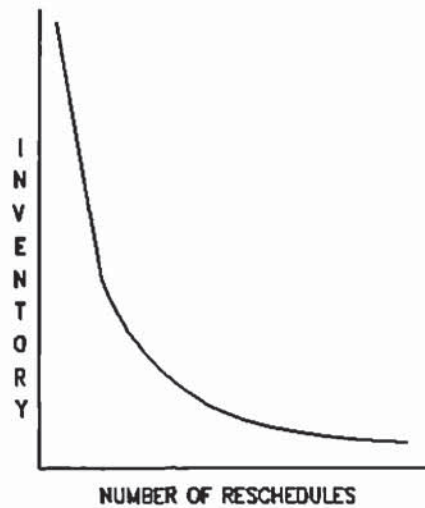


FIGURE 10-4 RELATIONSHIP BETWEEN NUMBER OF RESCHEDULES AND DAMPENING

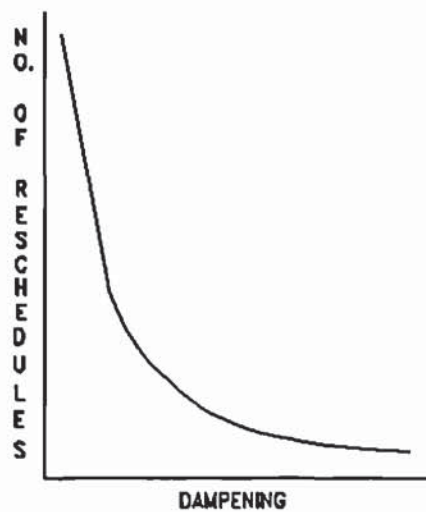


FIGURE 10-5 RELATIONSHIP BETWEEN INVENTORY AND DAMPENING

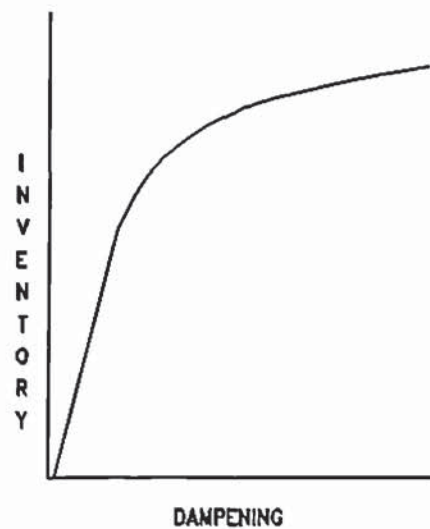


Table 10.5 - Relationship Between Dampening, Reschedules, and Excess Inventory

		<-----DAMPENING DAYS----->						
	VC	5	10	20	40	80	160	999
Inv	1	21.5	46.4	73.8	85.8	90.8	91.1	91.1
Ords	1	10.7	24.9	28.1	45.4	48.2	48.4	48.4
Inv/Ord	1	2.0	1.9	1.9	1.9	1.9	1.9	1.9
Inv	2	1.2	2.8	4.7	5.7	6.0	6.0	6.0
Ords	2	4.2	9.5	15.9	19.5	20.6	20.6	20.6
Inv/Ord	2	.3	.3	.3	.3	.3	.3	.3
Inv	3	.2	.8	1.2	1.7	2.0	2.0	2.0
Ords	3	2.2	4.3	9.7	13.7	15.3	15.3	15.3
Inv/Ord	3	.1	.1	.1	.1	.1	.1	.1
Inv	4	.0	.1	.3	.5	.6	.7	.7
Ords	4	.8	1.9	4.2	7.8	9.5	9.6	9.6
Inv/Ord	4	.0	.1	.1	.1	.1	.1	.1
Inv	5	.0	.0	.1	.1	.2	.2	.2
Ords	5	.1	.5	1.0	2.8	3.6	3.6	3.6
Inv/Ord	5	.0	.1	.1	.0	.0	.0	.0
Inv	6	.0	.0	.0	.0	.1	.1	.1
Ords	6	.0	.1	.3	1.2	2.2	2.4	2.4
Inv/Ord	6	.0	.0	.0	.0	.0	.0	.0
Inv	T	23.0	49.9	80.0	93.9	99.6	100	100
Ords	T	18.0	41.3	69.3	90.4	99.5	100	100
Inv/Ord	T	1.3	1.2	1.2	1.0	1.0	1	1

T = Total of VC 1,2,3,4,5,6

VC = Value Class

Inv = Excess inventory (as a fraction of the original rescheduled cycle stock)

Ords = No of orders dampened (as a fraction of the original number of reschedule-outs)

Inv/Ord = Ratio of Excess Inventory/No of orders dampened

Table 10.5 shows an extract from the results of the model. The parameter set which minimises the inventory increase for a given level of dampening are selected manually (by trial and error) from the table. An example is shown below.

Example 10.1 - Selecting Dampening Days

Assume that the following permutations of dampening days are selected for trial from the data in Table 10.5:

<u>Value Class</u>	<u>Dampening Days</u>	<u>Inventory</u>	<u>No of Orders</u>	<u>Dampening Days</u>	<u>Inventory</u>	<u>No of Orders</u>
1	5	21.5	10.7	5	21.5	10.7
2	5	1.2	4.2	10	2.8	9.5
3	10	0.8	4.3	20	1.2	9.7
4	20	0.3	4.2	40	0.5	7.8
5	40	0.1	2.8	80	0.2	3.6
6	80	0.1	2.2	160	0.1	2.4
	System Total	24.0	28.4		26.3	43.7

The first set of dampening days i.e. 5,5,10,20,40,80, will increase the total inventory level by 24.0% for a 28.4% reduction in the volume of reschedule-outs. The second set of parameters will increase the inventory level by 26.3 % for a 43.7 % reduction in the volume of reschedule-outs. Similarly, other permutations of dampening days can be tested. From the results, management are in a position to select a particular set of dampening days to use for the MRP system. For instance, from the above two sets, management may decide to choose the second set of parameters because for an additional increase of 2.3% (26.3 - 24.0) in inventory relative to the first set, a reduction of 15.3% (43.7 - 28.4) in the volume of reschedule-outs can be achieved.

10.5.1 Traditional Reschedule-Out Rule

As noted earlier, the majority of dampening rules are based on rescheduling costs. If the user is currently using such a rule and has no facility to implement the more simple rule described above, then the following method can be used to predict the performance of the system under the different rescheduling costs.

Like the EOQ based ordering rules, there are several variations in the cost based dampening rules. The basic rescheduling out formula in terms of rescheduling cost is:

$$RC = \frac{OV * ICR * RD}{Y} \dots\dots\dots (10.1)$$

Where

RC = Rescheduling Cost
OV = Critical Order Value
ICR = Inventory carrying rate (decimal)
RD = Reschedule-out days (movement)
Y = Number of working days in standard company year

Under such a rule, an order is recommended for rescheduling if the cost of holding inventory over the rescheduled horizon is greater than the cost of rescheduling. The rescheduling cost and the inventory carrying rate are set by the user. For an order to be rescheduled, the actual order value must be greater than the critical order value. Rearranging equation (10.1) in terms of the critical order value:

$$OV = \frac{RC * Y}{ICR * RD} \dots\dots\dots (10.2)$$

Example 10.2 - To Show how the Traditional Rule Works .

Assume as a result of a demand decrease for part number XYZ123, the MRP system calculates the new required date for an existing order to be 10 days later. The order value is £900. Will the order be rescheduled to the new date or suppressed under the following parameter set?

RC = £10
ICR = 25% (equivalent to 0.25)
Y = 250 days

Using equation 10.2, the critical order value under the given parameters and movement is:

$$OV = \frac{10 * 250}{0.25 * 10} = £1,000$$

The actual order value is lower than the critical order value (£1000) and therefore the order will be suppressed.

10.5.2 Replacing Costs by a Cost Ratio

In practice, as discussed in chapter 6, the cost of rescheduling and the cost of holding inventory are not easily determined. This limitation can be easily overcome in exactly the same fashion as was overcome in the ordering rule i.e. the ratio RC/ICR can be replaced by another controlling parameter K'. Note K' is used to distinguish it from the K used in the ordering/inventory ratio in chapter 8. By replacing the costs by a control variable K' means that K' can now be flexed to control the critical order value. Increasing the cost ratio will increase the critical order value. From equation 10.2, the critical order value is now:

$$\boxed{OV = \frac{K' * Y}{RD}} \dots\dots\dots (10.3)$$

Where

$$\boxed{K' = RC/ICR} \dots\dots\dots (10.4) \text{ The rescheduling cost ratio}$$

10.5.3 Investigating the Effect of Changing The Cost Ratio

The dampening effect of changing the cost ratio K' can be investigated using historical data. Again, this is an iterative process.

- Step 1 - Calculate the order movements for each order in the historical database.
- Step 2 - Set an initial value of K' and determine the critical order value for each order from equation 10.3.
- Step 3 - Compare the critical order value with the actual order value. If the actual order value is greater than the critical value then the order would have been rescheduled; if not then it would have been suppressed.

This procedure is repeated for each historical order. Counting the number of orders that would have been dampened and summing its order value will give the inventory impact under the given parameter set.

Step 4 - Repeat steps 2 and 3 until the parameters yield the desired dampening effect and an acceptable level of excess inventory.

Step 5 - Once a suitable combination of parameters have been found, the 'K' value can be decomposed (from equation 10.4) to determine the rescheduling cost and the inventory carrying rate to input into the MRP. As is seen from equation 10.1, the costs will always be used as a ratio. Therefore any permutation of costs can be selected as long as the cost ratio remains constant. For example, if the final value of K' chosen is 50, then from equation 10.4:

ICR can be set at 10% and RC at £5
or ICR at 20% and RC at £10
or ICR at 30% and RC at £15 etc...

In practice, the inventory carrying rate is generally fixed, therefore the rescheduling-out cost is easily calculated from equation 10.4.

10.5.4 Comments on Using Cost Ratio

The advantage of using the rule with a cost ratio is that management can now model the effect of the rule and control the amount of reschedules generated by the system. K' acts as a management control parameter. Increasing it will reduce the number of reschedules and vice-versa. However, this is a rather cumbersome dampening method because both the critical order value and the dampening days will affect the number of reschedules and inventory.

10.5.5 A Case Study

At IBM Havant, prior to implementing the new rescheduling-out rule a combination of both of the above rules were used i.e. the reschedules went through two filters -

the first stage checked the order movement and the second compared the order value with the critical order value.

Stage 1 - It first classifies the item according to the value class limits and then checks to see if the actual movement suggested is greater than the minimum rescheduling days for that class. If it is not then the order is suppressed and stage 2 is not initiated.

Stage 2 - If stage 1 is passed then the second stage is activated. This checks the order value. If the actual order value is greater than the critical order value then the order is rescheduled otherwise it is suppressed.

The only difference between the calculation used at IBM and the traditional rescheduling rule just discussed is that the IBM rule uses a pre-defined number of dampening days instead of the actual order movement to calculate the critical order value. The advantage of using pre-defined dampening is that the critical order value is fixed and is not a variable for each order as in the traditional rule. For example: Using $K' = 50$, $Y = 250$, and the dampening as below, the critical order value (from equation 10.3) is:

Value Class	Minimum Reschedule-Out Days	Critical Order Value
B1	1	12,500
B2	5	2,500
B3	10	1,250
B4	20	625
B5	40	312
B6	80	156

An order for an item in value class 'B2' will be rescheduled if and only if the order value is greater than £2,500 and the movement is greater than 5 days, otherwise it will be suppressed. Similarly, a class B3 item's order will be rescheduled if the order value is greater than £1,250 and the movement is greater than 10 days.

10.5.6 Comparison Between The Rescheduling-Out Rules

With the traditional rule, the limitations of determining the rescheduling costs are overcome by treating the costs as a cost ratio. The cost ratio now becomes a management control variable. The primary disadvantages of the more traditional rule is that the decision to dampen or reschedule is dependent on two dynamic variables - the actual value of the order and the actual size of the order movement, both of which change from order to order. This can cause confusion with the users. For instance, imagine the confusion a user faces when the system generates a rescheduling notice for one order and a suppression for another order of roughly the same order value and with only a slight difference between the order movements for the same part number. Such apparent conflicting recommendations will occur with orders near the edge of the critical order value. Clearly, although such a recommendation will be theoretically correct, based on the rescheduling and the inventory holding costs, it will cast doubt on the system's ability to generate valid recommendations because the average user will fail to understand the subtle difference between the two orders, thus increasing intervention and eventually discrediting the system. As discussed in earlier chapters, this is one of the major causes of MRP failures.

Similarly, IBM's double filter rule will also generate apparently conflicting recommendations. It is also very complex with the decisions not readily apparent. The only advantage of IBM's rule over the more traditional one is that both the critical order movement and critical order value are pre-defined, i.e. they do not depend on the actual values as in the case of the more traditional rule.

The same effect can ultimately be achieved as the new proposed rule; but both the traditional rule and IBM's rule are rather complex and give inconsistent recommendations. For these reasons the new proposed rule is preferred. The new rule developed is very simple and consistent with business logic.

A point worth noting again is that former researchers strived to develop optimum rules, but in their obsession, a vital fact was being overlooked - in a real dynamic environment, demands are constantly changing. Even assuming that the costs could

be determined, an optimum decision becomes invalid immediately after the system has run because requirements will change again.

The advantage of following the suggested procedures (which ever of the three rules is used) is that the volume of reschedules can now be controlled to achieve maximum benefit for a negligible increase in inventory. The increase in the number of reschedules in the higher value classes will be compensated by a reduction in the lower value classes.

10.6 Rescheduling-In Dampening Model

The rescheduling-in dampening principle is similar to the rescheduling-out principle. However, instead of setting dampening days, protection is used. The principle is that protection should increase as the value of the orders decreases. That is, low value class items should have a higher margin of protection while the high value items should have a lower degree of protection. Under this principle the high value class orders are rescheduled-in while the low value orders are dampened. An order is rescheduled-in only if a predefined percentage of the protection is consumed otherwise it is dampened.

10.6.1 The Reschedule-In Dampening Method

As discussed above, protection is set by value class and an order is rescheduled-in if the order movement is greater than a given percentage of the protection. A unique feature at IBM is that safety lead time (called protective schedule) is used rather than the more common safety stock. Therefore rescheduling-in decisions are based on the erosion of protective schedule (safety lead time) rather than the safety stock.

The dampening rule is:

$$\boxed{CM = PS * D} \quad \text{.....(10.5)}$$

Where	CM	= Critical movement (days)
	PS	= Protective schedule (days)
	D	= Dampening factor (%)

An order is dampened if the order movement is less than or equal to the critical movement. If it is greater than the critical movement then the order will be rescheduled-in. The dampening factor is defined by the user and was set at 80 percent at IBM Havant for all the value classes. The dampening factor effectively allows a percentage of the safety lead time to be eroded before an expediting notice is raised. The higher the dampening factor then the more of the protective schedule will be eroded before a remedial action is suggested. Table 10.6 shows the protection used at IBM Havant.

Table 10.6 - Protective Schedule and Dampening Factor		
Value Class	Protective Schedule	Dampening Factor
-----	-----	-----
B1	5	80 %
B2	5	80 %
B3	10	80 %
B4	20	80 %
B5	25	80 %
B6	35	80 %

10.6.2 Procedure For Determining Protective Schedule

The effect of changing the protective schedule and the dampening factor is modeled using the historical database described previously (see Appendix D). Again this is an iterative process.

- Step 1 -** Define an initial set of protective schedules and dampening factor by value class, for example, as shown in the Table 10.6 above and calculate the critical order movement using equation 10.5.
- Step 2 -** Using the historical database calculate the actual order movement for each order.

Step 3 - Compare the actual order movement with the critical order movement. If the actual order movement is greater than the critical value then the order would have been rescheduled; if not then it would have been suppressed.

This step must be repeated for all the historical orders. Counting the number of suppressed orders will give the degree of dampening that will be achieved.

Step 4 - Repeat the whole process for another set of parameters until an acceptable solution is reached.

10.6.3 Comments On The Rescheduling-In Rule

The advantage of setting a protective schedule by value class is that a higher level of protection can be applied over the low value items for a relatively small investment in inventory. Furthermore, because there is a higher level of protection over the low value parts, then a higher degree of dampening is achieved for a relatively small investment in inventory. On the other hand, a lower amount of protection is applied to the higher value items because the inventory investment is high. This limitation is not so critical because the higher value items will be under much tighter control as described by the ordering methodology earlier.

10.6.4 Characteristics of The Rescheduling-In Rule

Figure 10.6 shows the general characteristics of the model and Table 10.7 shows and extract from the results of the model. Again the parameter set which minimise the inventory to dampening impact can be selected manually (by trial and error) from the table. An example is shown below.

FIGURE 10-6

RELATIONSHIP BETWEEN PROTECTION
AND NUMBER OF RESCHEDULE-INS

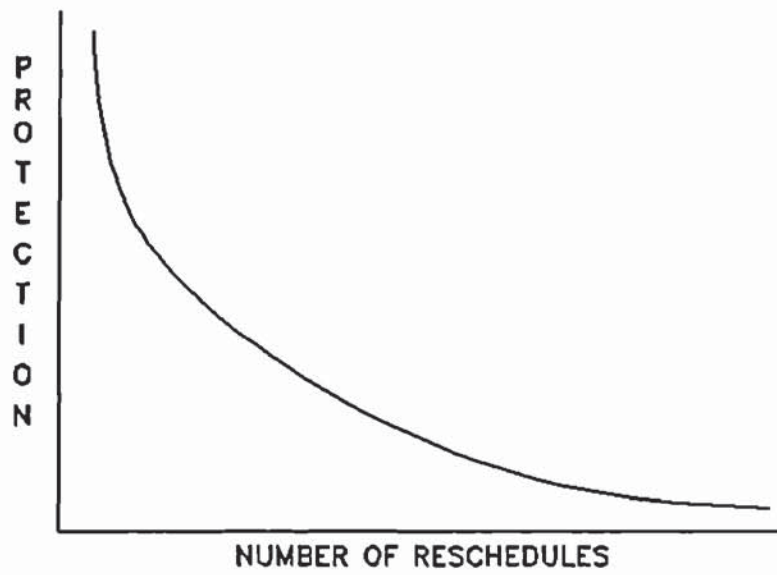


Table 10.7 Protective Schedule (Safety Stock)
and No of Reschedules

<-----PROTECTIVE SCHEDULE----->									
	VC	5	10	15	20	40	80	160	999
SS	1	21.5	46.4	64.0	73.8	85.8	90.8	91.1	91.1
Ords	1	10.7	24.9	33.0	38.1	45.4	48.2	48.4	48.4
SS/Ord	1	2.0	1.9	1.9	1.9	1.9	1.9	1.9	1.9
SS	2	1.2	2.8	4.1	4.7	5.7	6.0	6.0	6.0
Ords	2	4.2	9.5	13.6	15.9	19.5	20.6	20.6	20.6
SS/Ord	2	.3	.3	.3	.3	.3	.3	.3	.3
SS	3	.2	.5	.8	1.2	1.7	2.0	2.0	2.0
Ords	3	2.2	4.3	7.0	9.7	13.7	15.3	15.3	15.3
SS/Ord	3	.1	.1	.1	.1	.1	.1	.1	.1
SS	4	.0	.1	.2	.3	.5	.6	.7	.7
Ords	4	.8	1.9	2.8	4.2	7.8	9.5	9.6	9.6
SS/Ord	4	.0	.1	.1	.1	.1	.1	.1	.1
SS	5	.0	.0	.0	.1	.1	.2	.2	.2
Ords	5	.1	.5	.7	1.0	2.8	3.6	3.6	3.6
SS/Ord	5	.0	.1	.1	.1	.0	.0	.0	.0
SS	6	.0	.0	.0	.0	.0	.1	.1	.1
Ords	6	.0	.1	.2	.3	1.2	2.2	2.4	2.4
SS/Ord	6	.0	.0	.0	.0	.0	.0	.0	.0
SS	T	23.0	49.9	69.2	80.0	93.9	99.6	100	100
Ords	T	18.0	41.3	57.4	69.3	90.4	99.5	100	100
Inv/Ord	T	1.3	1.2	1.2	1.2	1.0	1.0	1	1

T = Total of VC 1,2,3,4,5,6

VC = Value Class

SS = Safety stock (as a fraction of the original)

Ords = No of orders dampened (as a fraction of the original number of reschedule-ins)

Inv/Ord = Ratio of Safety Stock/No of orders dampened

Example 10.3 - Selecting Protective Schedule Days

Assume that the following permutations of protective schedule days are selected for trial from the data in Table 10.7:

<u>VC</u>	<u>Protective Schedule (Days)</u>	<u>Safety Stock</u>	<u>No of Orders</u>	<u>Protective Schedule (Days)</u>	<u>Safety Stock</u>	<u>No of Orders</u>
1	5	21.5	10.7	5	21.5	10.7
2	5	1.2	4.2	10	2.8	9.5
3	10	0.5	4.3	15	0.8	7.0
4	20	0.3	4.2	20	0.5	4.2
5	40	0.1	2.8	40	0.2	2.8
6	40	0.0	1.2	40	0.1	1.2
System Total		23.6	27.4		25.9	35.4

In this case, the first set of protective schedule days i.e. 5,5,10,20,40,40, will increase the total safety stock level by 23.6% for a 27.4% reduction in the volume of reschedule-ins. The second set of parameters will increase the inventory level by 25.9 % for a 35.4 % reduction in the volume of reschedule-ins. Similarly, other permutations of parameters can be tested. From the results, management are in a position to select a particular set of protective schedule days to use for the MRP system. For instance, from the above two sets, management may decide to choose the second set of parameters because for an additional increase of 2.3% (25.9 - 23.6) in inventory relative to the first set, an additional reduction of 8.0% (35.4 - 27.4) in the volume of reschedule-ins can be achieved.

10.7 Advantages of the Dampening Methodology

This research took the opportunity to investigate how reschedules affected vendor delivery performance. In talking to the buyers at IBM, it was found that vendors encountered great difficulties in meeting the delivery performances when orders were frequently rescheduled. Their view was that the actual reschedules were not the problem, the problem was the frequent rescheduling of the same orders.

The advantage of the methodology described here is that it suppresses small movement; an order is only rescheduled when there is a significant movement relative to its value i.e. the lower value class orders must move relatively more than a higher

value class order. The advantage of following this methodology is that the volume of reschedules is controlled to achieve maximum benefit for a minimum investment in inventory. The increase in the number of reschedules in the higher value classes is compensated by a reduction in the lower value classes.

10.8 Adapting the Rules

The dampening methodology was implemented at IBM Havant. The actual results are presented in chapter 12. The dampening rules proposed are very simple. It should take very little programming effort to incorporate them into any existing MRP suite. However, if the user has not the programming facilities, then the same effect can be achieved by filtering the reschedule notices through a suitable database utility.

Chapter 11

Defining Optimum Safety Stock

11.1 Introduction

Unlike the reorder point systems, safety stock under MRP is supposedly redundant due to the system's ability to replan orders. This is technically true, but in practice, very close-in changes in demand or supply cannot be met by replanning alone. For this reason some form of safety stock is held either through a formal buffering policy or informally through generous or inflated lead times.

Buffering is a necessary evil and it obviously adds costs. Therefore many users have reduced or eliminated holding formal stock of made-in parts because they have some degree of control over their manufacturing process. However, most companies feel that purchased raw materials and components are outside their direct control and therefore prefer to carry safety stock through a formal policy to protect against fluctuations in demands and supplies.

Despite the wide-spread use of safety stock (or some form of safety lead time), simple, practical, and effective approaches to monitor the actual consumption of safety stock/safety lead time are not available. If the consumption is not monitored then the opportunities to reduce inventory are not clear. Also in practice, safety stock is set using some sort of blanket protection policy. Although such a policy is simple, it is ineffective and does not take account of the various sources of uncertainty, (which were discussed in chapter 4.2), acting in combination.

In this chapter a method is developed to set optimum amounts of protection and monitor its actual consumption. Also a simple strategy is described to reduce safety stock progressively.

11.2 Appraisal of Previous Research

As indicated in chapter 4.2, there are many sources of uncertainties acting together in practice. For instance, there are uncertainties in:

- a. demands (actual demand v forecasts)
- b. delivery timings
- c. delivery quantities
- d. scrap, quality, yields etc.

However, traditional research, even as late as 1988 (e.g. Hsu & El-Najdawi) has failed to address the effects of various uncertainties acting in combination. It only focuses on standard deviations of the demand forecast errors and service levels. The concept of relating safety stock /safety lead time to service levels is an attractive one from a theoretical view point. Through statistical methods it is relatively easy to calculate the level of safety stock required for a desired service level. This an a priori approach - where parameters are set in advance according to desired service level sounds far superior than rule-of-thumb or the trial-and-error approaches. Therefore it has held a great appeal to researchers and as such has received wide spread research efforts e.g. Steele (1975), Minifie & Heard (1976), Whybark & Williams (1976), Kropp et al. (1979), Wemmerlov (1979), Lowerre (1985) amongst many others.

11.3 Appraisal of Industrial Practices

In practice, (as was noted in chapter 4.2), because of the complexities and the limitations of statistical methods, some form of "blanket" protection is typically applied. It is common to find that safety stock is set by ABC categories through such rules-of-thumb as:

- a. one week's supply of safety stock for category 'A' items, two week's supply for category 'B' items and so on;
- b. or as a percentage of the gross annual demand.

Such rules are simple to set up and understand. They overcome the limitations and problems of measuring forecast errors, delivery performances etc. individually.

However, such rules have resulted in high operational inventories and relatively poor service. This is because the high stock are of things that are not necessary and/or protection is applied where it is not required. To maximise service for a minimum investment in inventory it is prudent to switch protection from the less critical items to the more critical items - Figures 11.1 and 11.2.

FIGURE 11-1

EXAMPLE OF OVER-PROTECTION

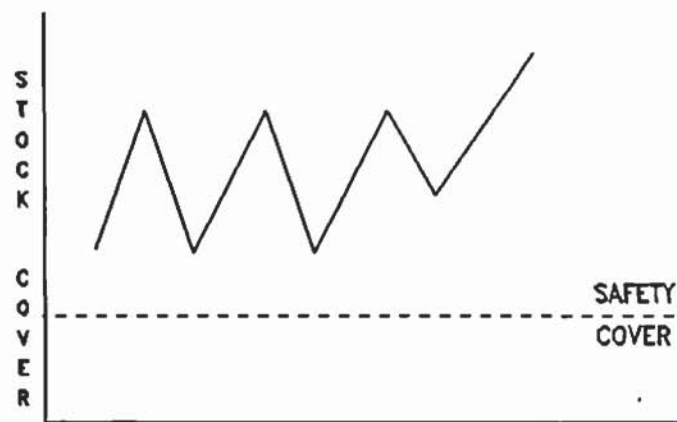
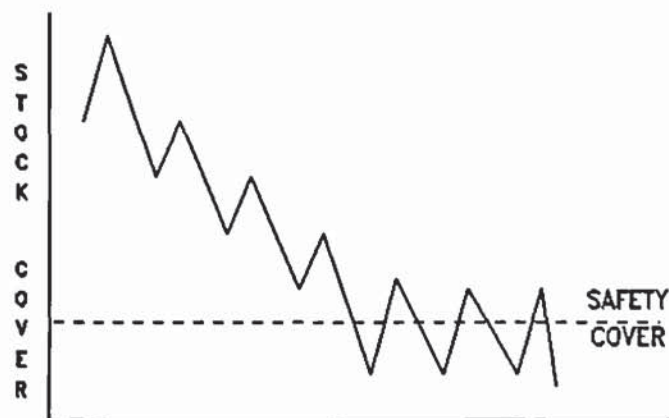


FIGURE 11-2

EXAMPLE OF UNDER-PROTECTION



This balance has been difficult to achieve in practice because the actual consumption of safety stock is not monitored. This was first noted by Wemmerlov (1979). The current research indicates that this position has not changed. The reason for this is that currently, simple procedures and methods are not available to monitor the consumption of safety stock. If safety stock is never consumed, then it is only excess inventory and every attempt should be made to reduce it.

11.4 Strategy to Reduce Safety Stock

Setting a service level, whether using statistical or other approaches, does not mean that it will be achieved in practice. A multitude of other factors not incorporated in the models influence the service actually achieved. Despite the obvious needs and advantages of holding buffers, working towards JIT means chipping away at the uncertainty and so being able to reduce buffers. However as mentioned earlier, it is usually difficult to reduce inventory because it is not monitored. Because of such difficulties, a strategy is required to reduce safety stock gradually in true JIT fashion. One such strategy proposed through this research and implemented at IBM is:

1. Implement the ordering policy discussed in chapter 8 to minimise cycle inventory for a given level of order workload.
2. Set blanket safety stocks or safety lead time for each annual usage value (ABC) category .
3. By using the new monitoring method which is described later, monitor items and ascertain whether the safety stock can be lowered. (The bulk of the inventory investment should be in the high usage value items. Therefore it is only necessary to monitor the high usage value items for maximum benefit).

11.5 Method to Monitor Safety Stock Consumption

Buffers are held both formally and informally. A formal policy may be to hold safety stock of so many weeks or so many standard deviations of demand. Informally, buffering is created through generous lead time settings - this is not the same as safety

lead time. (Refer to chapter 5). It is common for both formal and informal buffers to exist concurrently. Consequently it is not easy to assess what buffer stocks are held or consumed at any one time.

A method which overcomes these limitations is now discussed. The method is based on monitoring the actual on-hand inventory and converting it into stock cover i.e number of days the stock on- hand will cover current requirements.

11.5.1 Stock Cover/Coverage

The on-hand inventory is monitored at a regular interval, say weekly. Stock cover or coverage is then calculated by netting the on-hand inventory against the current requirements - current at the time of review.

Example 11.1 - Calculating Stock Cover in Days

On-hand Stock = 100, current production day = 01

Production Day:	01	02	03	04	05	06	07	09	10
	--	--	--	--	--	--	--	--	--
Demand:	20	10	10	20	30	10	20	20	10
Net Stock:	80	70	60	40	10	0	-	-	-

Stock exhaust date = 06

The stock exhaust date minus the current (review) date is defined as stock cover (in production days).

Therefore, stock cover = stock exhaust date - current date
= 06-01 = 5 days in this example

Stock cover is plotted on a chart such as the one shown in Figure 11.3. The solid line represents stock cover. Stock cover represents how many days the existing on-hand stock will last. The dotted lower line in Figure 11.3 represents the safety limit or safety cover. This is equivalent to safety lead time (protective schedule). If safety quantity is used instead of safety lead time then it is first necessary to convert the safety quantity into a corresponding average safety stock cover. This is simply given by dividing the average "daily going rate" with the safety stock as shown in Example 11.2.

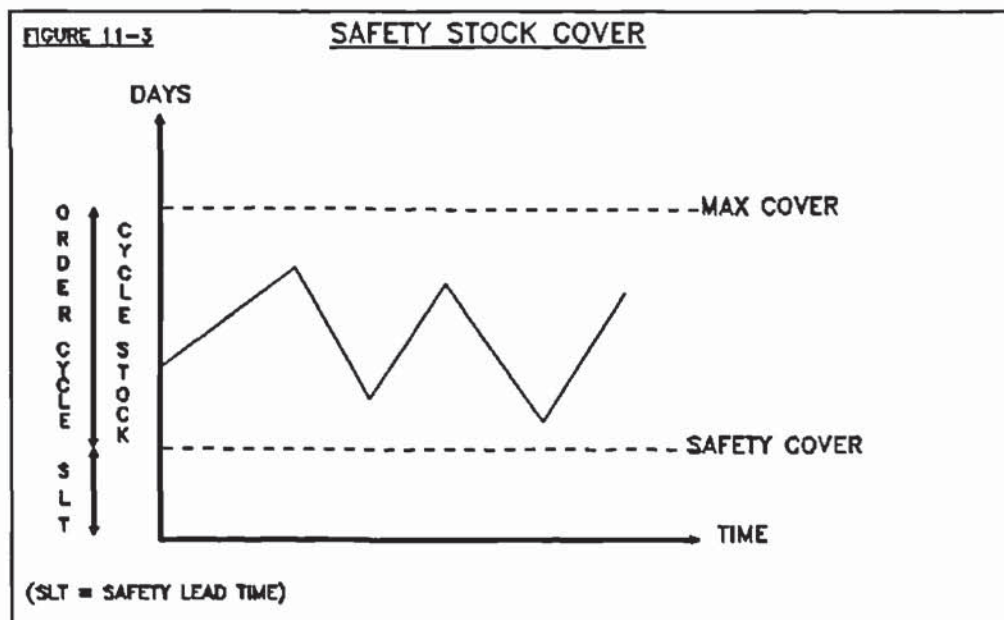
Example 11.2 -Converting Safety Quantity into Safety Cover

Safety Stock = 1000 units
Annual Requirement = 25,000 units
Standard Year = 250 days

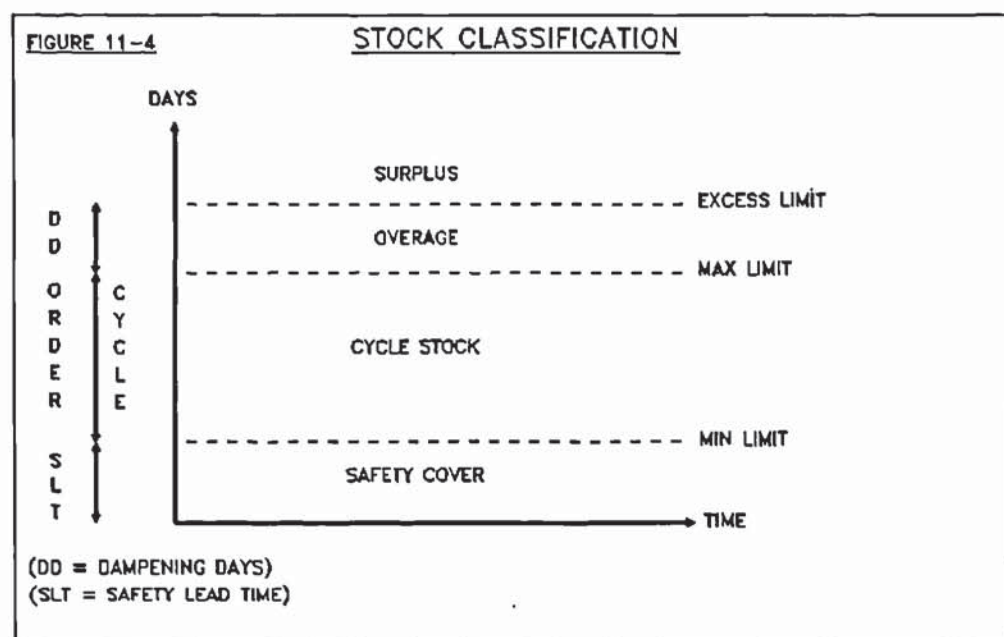
Daily Going Rate = Annual Requirements/Standard Year
= 25,000/250
= 100 units per day

Planned Safety Cover = Safety Stock/Daily Going Rate
= 1,000/100
= 10 days

If the inventory control process is under control then the actual stock cover should be between the safety level and the maximum limit as shown in Figure 11.3. These limits effectively act as the control limits and are analogous to statistical process control limits. Later it will be discussed how these limits can be used to trigger action. If the stock cover is outside the maximum planned limit then it is excess. To gain a greater degree of control, the excess stock can be sub-divided into "OVERAGE" and "SURPLUS" - terms which are used at IBM.



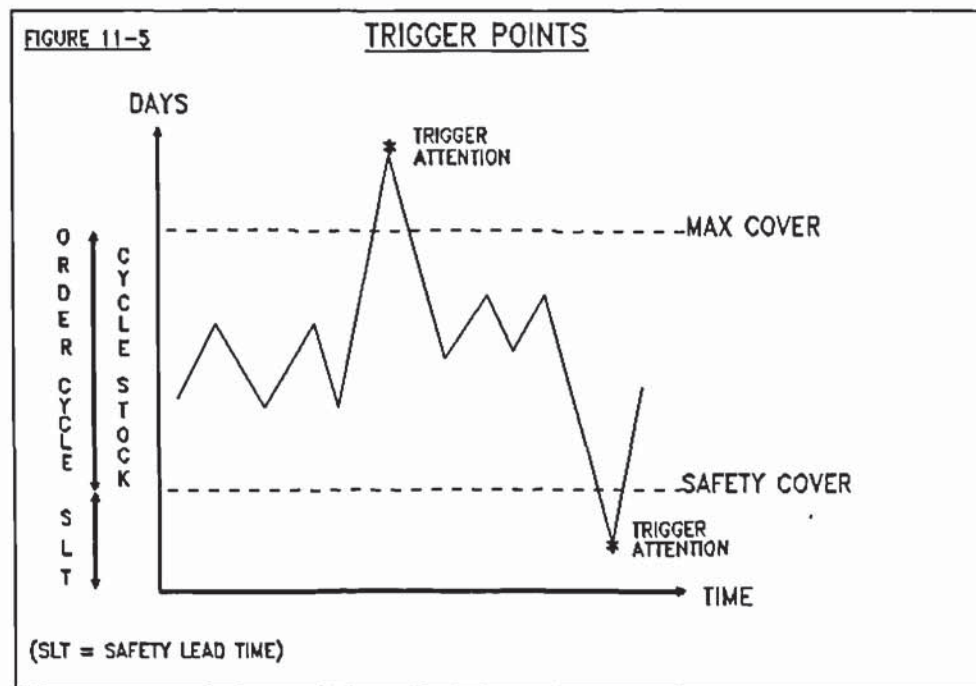
'Overage' represents inventory that will be dissipated within the near future whereas 'Surplus' represents inventory that is unlikely to be dissipated within the foreseeable future, and thus it is at risk of becoming obsolete. Figure 11.4 shows the stock classification. The overage limit is equal to the rescheduling-out dampening days discussed in the previous chapter, i.e. it represents inventory that has resulted from the dampening actions. On the other hand, the surplus limit can either be set arbitrarily or set to represent business risk i.e. deteriorations, obsolescence etc. (Within the electronics industries, product life cycles are getting shorter and shorter. Some products at the industrial partner have typical life cycles of 18 to 24 months - thus on these products the surplus limit can be set at say 18 months and reduced during the life of the product). Surplus stock can either be scrapped or written off.



11.5.2 Trigger Points

In practice with a large number of parts to control, it is not feasible to view each part every cycle. For this reason it is logical to only review exceptions. But how can the system identify exceptions? To define an exception, some form of trigger points are required. Further research is required to define such limits. However, as an initial

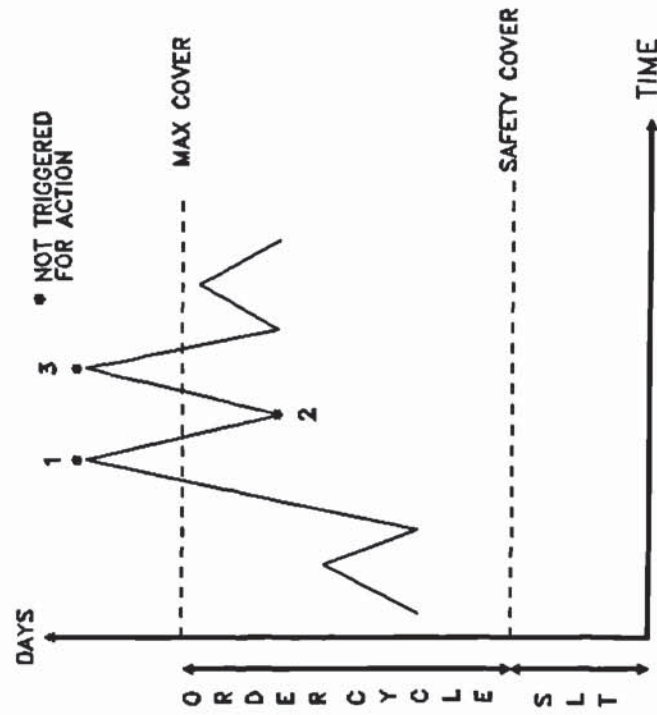
suggestion, the trigger points could be the minimum and maximum planned stock cover limits. These are the action or attention limits. For instance, if the stock cover is outside these limits, then the system can flag up that part for attention. Figure 11.5 shows such an example. Obviously if safety stock is used then it is expected that some safety stock should be used. Therefore, the lower trigger limit could be set lower than the minimum stock cover line.



To avoid the parts being flagged due to random and infrequent factors, the trigger points can be set such that the system only flags them if the control limits are broken a pre-defined number of times over a pre-defined horizon. For instance, the rule can be set to fire if the limits are broken, say, three times (in the same direction) over a three months period. Figures 11.6 and 11.7 shows such examples.

FIGURE 11-6

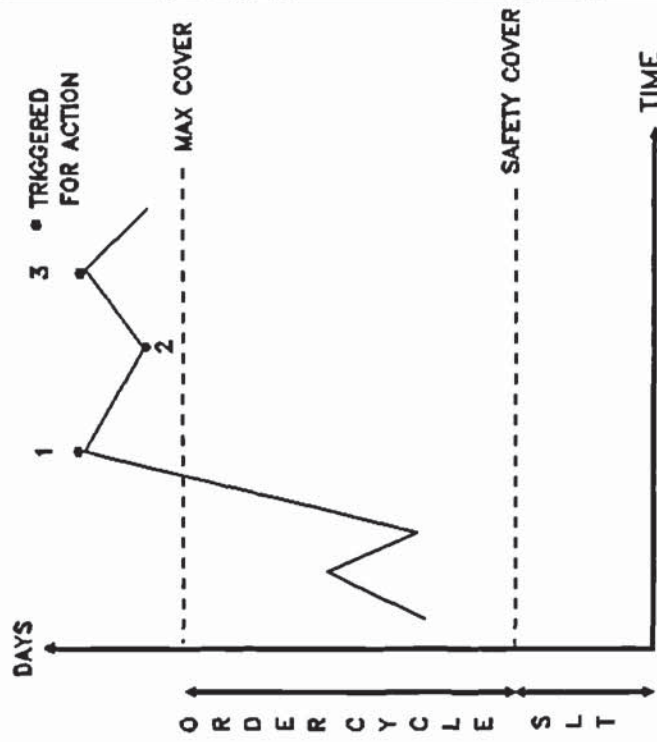
TRIGGER RULE



(SLT = SAFETY LEAD TIME)

FIGURE 11-7

TRIGGER RULE



(SLT = SAFETY LEAD TIME)

11.5.3 Switching Protection

Using the monitoring method discussed it will become apparent over time which items are being over protected and which are under protected. For example, if the stock cover for an item is such as shown in Figures 11.6 or 11.7, then clearly the item is over protected. It represents an opportunity to reduce protection. The value of safety reduced could then be used to increase protection on another part which is more critical. This method represents an opportunity to switch protection from the less critical items to more critical items in a systematic manner without increasing the total inventory in the system.

11.5.4 Stock Cover - Discussions

This approach views the total effect of all the different sources of errors. The advantage of using stock cover is that it shows the actual stock position. It is independent of demand variations and/or supply variations i.e. whether there is a demand change or supply change, the stock cover will always account for it. This is adequate from a production and inventory control point of view. Their objective is to ensure sufficient stocks are available to maintain production without line stoppages due to shortages. Therefore, it is only relevant to know the total error rather than understand whether the low stock cover (consequently on-hand inventory) is caused by an increase in the demands, or a late delivery, or quality problems. This is not to say that identifying individual sources of errors is not important for future improvements.

The importance of using the actual stock cover is that it represents the true inventory position at any given point in time. It overcomes the problems of the buyers moving order due dates on the vendor but not changing the dates on the system as discussed earlier in chapter 10. Whether an order is delivered late or early, it will be reflected in the stock cover. Whether a vendor ships poor quality or short, it again will be reflected in the stock cover. If there is high line scrap, it will be reflected in the stock cover.

Monitoring stock cover also overcomes the limitations of poor planning. For instance, if the planners consistently over forecast then the actual stock cover will be higher than the maximum planned cover. If they are consistently under-planning then the stock cover will be consequently lower than the minimum level i.e. the safety cover is being eroded.

Finally, the difference between just monitoring stock and calculating stock cover is that stock does not reveal whether it is sufficient to meet production or whether it is excess, but stock cover reveals both. This method can now be used to target safety stock to where it is actually required.

11.5.5 Effect Of Review Frequency

The higher the review frequency, then the tighter the control can be. Reviewing more frequently simply means a more detailed picture is available. From this research it was found that a weekly review frequency was adequate with the industrial partner because their production plans were set in weekly buckets. With a large number of parts, a more frequent review is not practical or desirable. On the other hand, a less frequent review cycle does not give sufficient detail to take actions.

11.6 Average Inventory, Cycle Stock, and Safety Stock

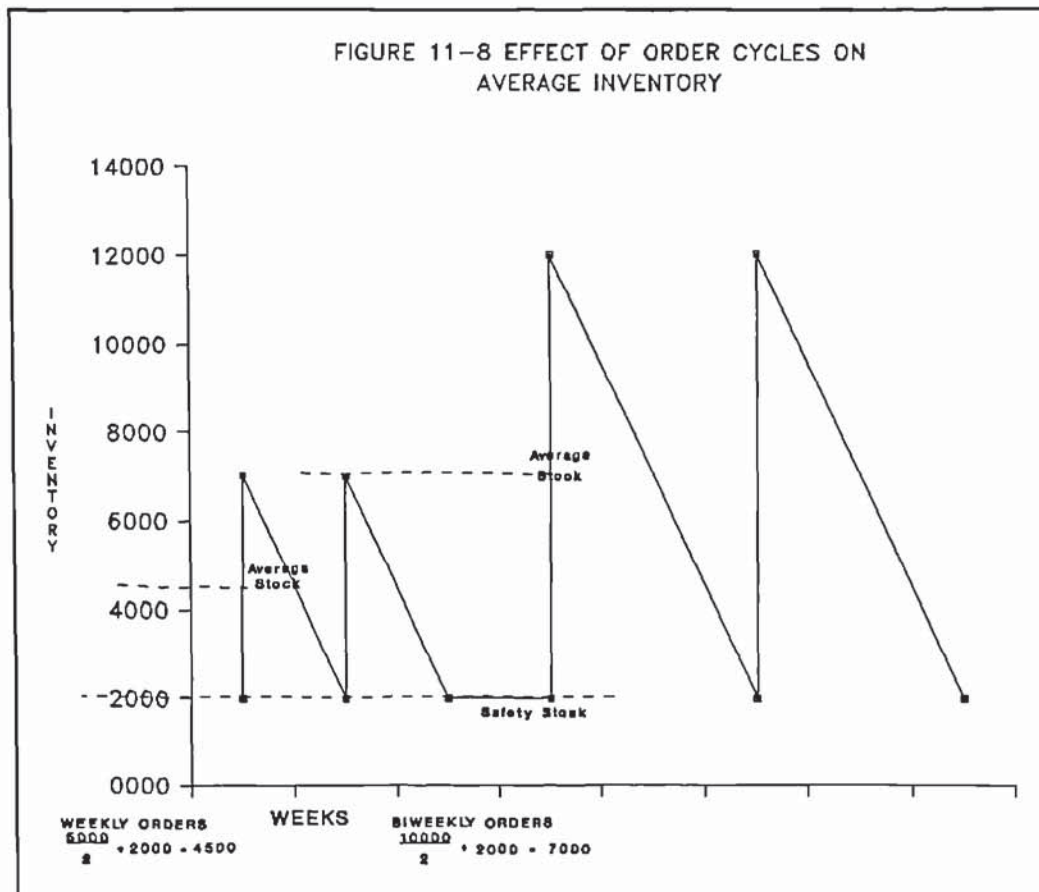
Many treat safety stock independent of cycle stock, (cycle stock is equivalent to the order size or order cycle); but as discussed by Orlicky (1975), safety stock is strongly related to order size. The effect is demonstrated by way of a simple example below:

For example, if a weekly delivery is 5000 units with a safety stock of 2000 units, then it would result in an average inventory of 4500 units, assuming that the inventory is consumed evenly.

$$\text{(Average Inventory = 1/2 Cycle Stock + Safety Stock)}$$

Under MRP, safety stock is always maintained. When the inventory reaches the safety level, a new order will be scheduled. Immediately the order comes in, the on-hand

inventory would again be at the maximum level and so on through the cycle. If the same item was ordered biweekly, the order quantity would be 10000 units (2×5000) and the average inventory would be 7000 units ($1/2 \times 10000 + 2000$). This is almost one and half times larger than the result of ordering weekly. Figure 11.8 shows the effect of order cycle on total inventory.



From Figure 11.8, it is clear that order cycle affects the average level of inventory. Increasing the order cycle will increase the average level of inventory and therefore more of the demand can be met from cycle inventory before consuming any safety stock. As Orlicky (1975) suggested, this represents an opportunity to reduce safety stock whilst maintaining service levels. Also from the figure, it is clear that safety stock should not be set independently of the order cycle.

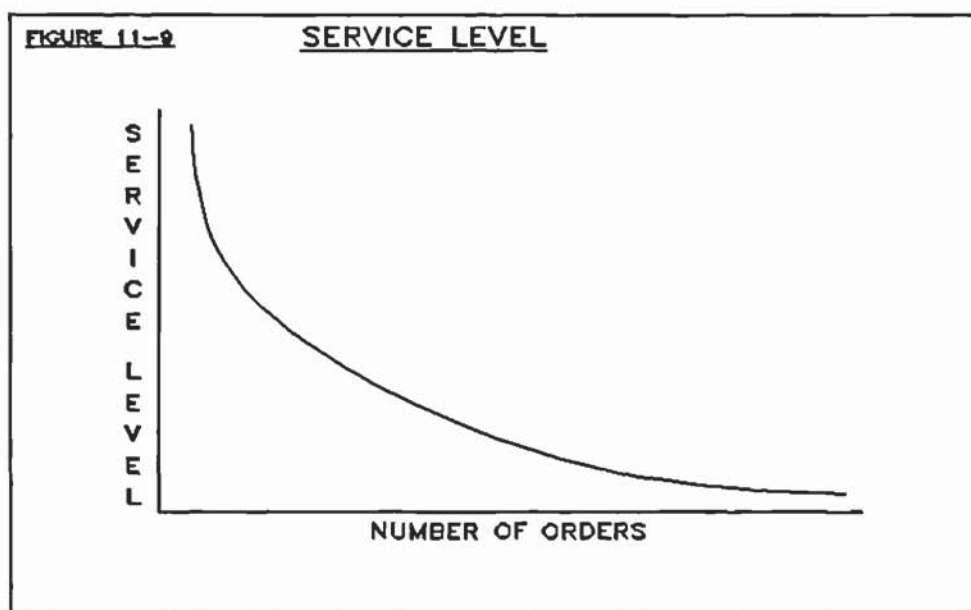
11.7 Service Level and Order Cycles

From chapter 8, it was noted that to reduce inventory, the ordering frequency must be increased. The traditional assumption is that service level will decrease as the ordering frequency is increased i.e. as the number or lots (orders) per year are increased. To put it in another way, the number of shortages will increase as the number of orders are increased. This assumption seems logical at first and unfortunately has prevented many MRP users implementing policies to increase the number of orders/deliveries per year. Their thinking has been shaped by statisticians rather than experience.

It is common for researchers to assume that for a given purchased order released on a given date, the probability that it will be delivered to stock on time $[P_{(t)}]$ and in the correct ordered quantity $[P_{(q)}]$ is the product of the independent probabilities i.e. $[P_{(t)} * P_{(q)}]$. If "n" number of lots are ordered during the year, the probability that all will meet the plan is the product of the n individual probabilities. This product, SL, is a measure of the expected service or service level.

$$SL = [P_{(t)} * P_{(q)}]_1 * [P_{(t)} * P_{(q)}]_2 * \dots * [P_{(t)} * P_{(q)}]_n$$

The general relationship between the expected service level and number of orders under this assumption is shown in Figure 11.9.



11.7.1 Traditional Theory - Fallacies and Omissions

The most important fallacy in the above theory is that once an order is placed, no action is taken until the order is delivered or the stock runs out. In practice, buyers usually know vendors that have delivery or quality problems and planners usually know how product mix fluctuates and know the manufacturing areas that tend to have production problems. By close liaison there is a good knowledge of which items are critical or will become critical. There is often frequent and constant contact with suppliers of such items thus reducing the risk of shortages.

Another fallacy with the traditional theory is that it assumes deliveries that are the most late are the ones which cause the stock-outs, and therefore safety stock should be related to them. It often happens that an order is delivered late because there is no "urgency" for it. This is often because buyers expedite some orders from a supplier and in return the supplier is allowed to reschedule-out some other less critical orders, but very often the buyers do not update the original due date of such orders and consequently they appear to have been delivered late.

11.7.2 Working Towards JIT

With the increasing attention paid to JIT and supplier integration, it is likely that the number of shortages will decrease as smaller more frequent orders are placed. This assumption is supported by two factors:

1. Smaller and more frequent orders lead to a smoother vendor schedule. (The benefits of such schedules were discussed in chapter 2 where it was noted that it is one of the fundamental factors in the Japanese success story).

Assuming the vendor produces according to the schedule, then at any given point in time, there will be less outstanding work left on a batch of the components than would be the case if the batches were much larger. Therefore, the expediting lead time is much smaller than would have been otherwise. The advantage of a shorter expediting lead time is that the vendor can react rapidly to front end schedule changes thus minimising risk of shortages. Also regular batches means that there will be fewer

unplanned set-ups for the vendor - thus minimising disruptions.

2. Smaller more frequent orders means the supply "pipe-line" is much more fluid, thus the risk of critical shortages are minimised. If a shortage does occur, then it will be short lived because of the supply fluidity. Also in a repetitive environment, assemblies are assembled one at a time. So by the time the last component is consumed it is likely another batch (at least a partial batch) will be received in time to maintain production.

At this stage it may be useful to draw the distinction between frequency of stock-outs i.e. how often shortages occur and length of the shortages i.e. how long the assembly line is stopped. Obviously, both type of shortages are critical under different circumstances. This research found that in a repetitive assembly operation, the length of the shortage is much more critical than the frequency of shortages. A long stoppage at any stage of the assembly process will accumulate excessive WIP in front of the affected operation and starve subsequent operations. A short stoppage, on the other hand, will be less disruptive because there is generally sufficient WIP to maintain production for a short while.

It is clear that there exists a distinction between critical and non-critical shortages. Critical shortages are those that will actually stop the production line, these are classified as 'Type A' shortages at IBM; whereas non-critical shortages are those that have failed to meet the original planned due dates. This distinction has not been recognised by most previous research and is one of the reasons limiting the value of earlier theories.

11.8 Summary

MRP systems are designed to align order due dates against the changing requirements. However, close-in changes cannot be met by rescheduling changes. The common practice is to use either safety stock or safety lead time to protect against close-in changes.

There are numerous strategies for setting the safety stock. Statisticians, for example, recommend that safety stock should be set against historical demand forecast errors. The mathematical formulas for these methods are often complex and therefore are not widely applied - indeed if at all. This argument is supported by Wemmerlov (1979), who from his survey found little evidence that protection was set using formal procedures and statistical analysis. Another limitation of such statistical methods is that they do not take account of the various other uncertainties such as scrap, late delivery, short quantities etc. acting simultaneously.

In practice, there are no systematic methods of setting safety stock. The more common practice is to set "blanket" protection by Pareto classes. The problem with blanket protection is that, for a given inventory investment some items are over protected whilst others suffer from shortages (under protection). To maximise service it is logical to switch some of the protection from the less critical items to the more critical items. However, this is found to be difficult to achieve because currently there are no mechanisms available to monitor the actual consumption of the safety stock. If consumption is not monitored then safety stock cannot be reduced.

In this chapter a method to set protection was developed to buffer against multiple variations acting in combination which the more traditional approaches have failed to address. Using the proposed method, the stock cover can be monitored and increased or decreased where necessary. Thus over time an optimum balance is reached where each part number in the system can have the appropriate amount of protection.

Chapter 12

Results & Discussions

12.1 Introduction

In chapter 7 the ordering strategy was discussed followed by a detailed description of the ordering and rescheduling methodologies in the subsequent chapters. The ordering and rescheduling methodologies are developed as iteration models through which the effect of various parameter sets can be simulated. IBM's operations were simulated using these iteration models. With the models the existing base position was determined together with a number of target positions from which the IBM management team agreed to implement one of the proposals.

This chapter presents the results from the iteration model and compares them with how the system actually performed at IBM Havant over a period of over 2 years between 1989 to 1991. The iteration models were used to predict and set the parameters to control:

- a. the volume of new order recommendations
- b. the volume of reschedule-out notices
- c. the volume of reschedule-in notices
- d. inventory

Also, it was predicted that implementing the parameters recommended by the models would reduce the number of order cancellations and improve MRP compliance. (Compliance is a measure of how many of the recommendations are complied with without manual alterations).

12.2 Ordering Parameters

Using the iteration model a new set of value class limits and order cycles were proposed. The proposed parameter set would reduce inventory at the expense of increasing the number of order/delivery recommendations. In addition the proposed parameter set would transfer workload from the low to the high value class as

discussed in the ordering strategy in chapter 7.

IBM Havant generally suffer from schedule cuts. The advantage of the proposed parameters is that the high value items are ordered more frequently and in smaller lots. Consequently, if there is a schedule cut then the value of the pipeline inventory will be smaller and thus it would result in less excess inventory than would have been the case otherwise.

Before the parameters were implemented, approval had to be gained from all areas of the organisation - inventory, purchasing, receiving, and transport. Obviously, the inventory planners will have no objections in reducing the inventory level. However, if the number of order/delivery recommendations are increased then all the other functions will be affected by the increase. The purchasing function has to balance the extra workload against their current level of capacity. The receiving department must ensure that the extra volume of deliveries is within their existing capacity. The transport function must ensure that they can meet the increase in delivery rate without significant increase in the transportation costs - detailed analysis showed that the transportation costs would not be affected because all the parts affected were on the contracted carriers' existing schedules.

12.3 Rescheduling Parameters

Obviously, increasing the number of orders in the system will increase the MRP nervousness. To reduce the nervousness, dampening parameters were also implemented in conjunction with the ordering parameters.

The iteration model was used to determine the rescheduling parameters to gain maximum stability and reduction in system nervousness for a minimum investment in inventory. (As discussed in chapter 10, dampening reschedule-outs will result in excess inventory and extra protective stock must be introduced to dampen reschedule-ins).

In order to enable the purchasing department to assess the impact of the ordering and rescheduling parameters, detailed analysis was carried out by part number. It was found that the net effect of increasing the number of new recommendations and reducing the volume of reschedules was that the total buyer workload would decrease significantly.

12.4 Parameter Proposal

The calculations were based on a year's historical data. This data was used to project the performance of the system under the new set of parameters. Table 12.1 shows the final proposal that was implemented.

Table 12.1 - Parameter Proposal					
<u>Value Class</u>	<u>Upper Value Class Limit (pounds)</u>	<u>Order Cycles (Days)</u>	<u>Minimum Resch-out (Days)</u>	<u>Protective Schedule (Days)</u>	<u>Dampening Factor</u>
1	999,999,999	5	5	5	80%
2	110,000	10	5	5	80%
3	27,500	20	10	15	80%
4	7,000	40	20	20	80%
5	1,700	80	40	25	80%
6	400	240	80	35	80%

Under this parameter proposal the iteration model predicted the following benefits:

	<u>Change</u>	<u>Inventory Benefit</u>
No of New Recommendations	= +20 %	-£1.7 M
No of Reschedules	= -30 %	+£0.2 M
Total Order Base	= -8 %	-£1.5 M
The 'total order base' includes new recommendations, reschedule-ins, reschedule-outs, and cancellations.		

Further, detailed analysis of the historical order base showed that the MRP compliance would go up by at least 8 percent under the proposed parameter set. This

was because more orders would fall within the previously accepted order value range. Also the proposed parameter set will enable Havant to achieve an 'intervention free' system, stabilize the MRP outputs and also facilitate the purchasing department to implement JIT purchasing schedules.

12.5 Results

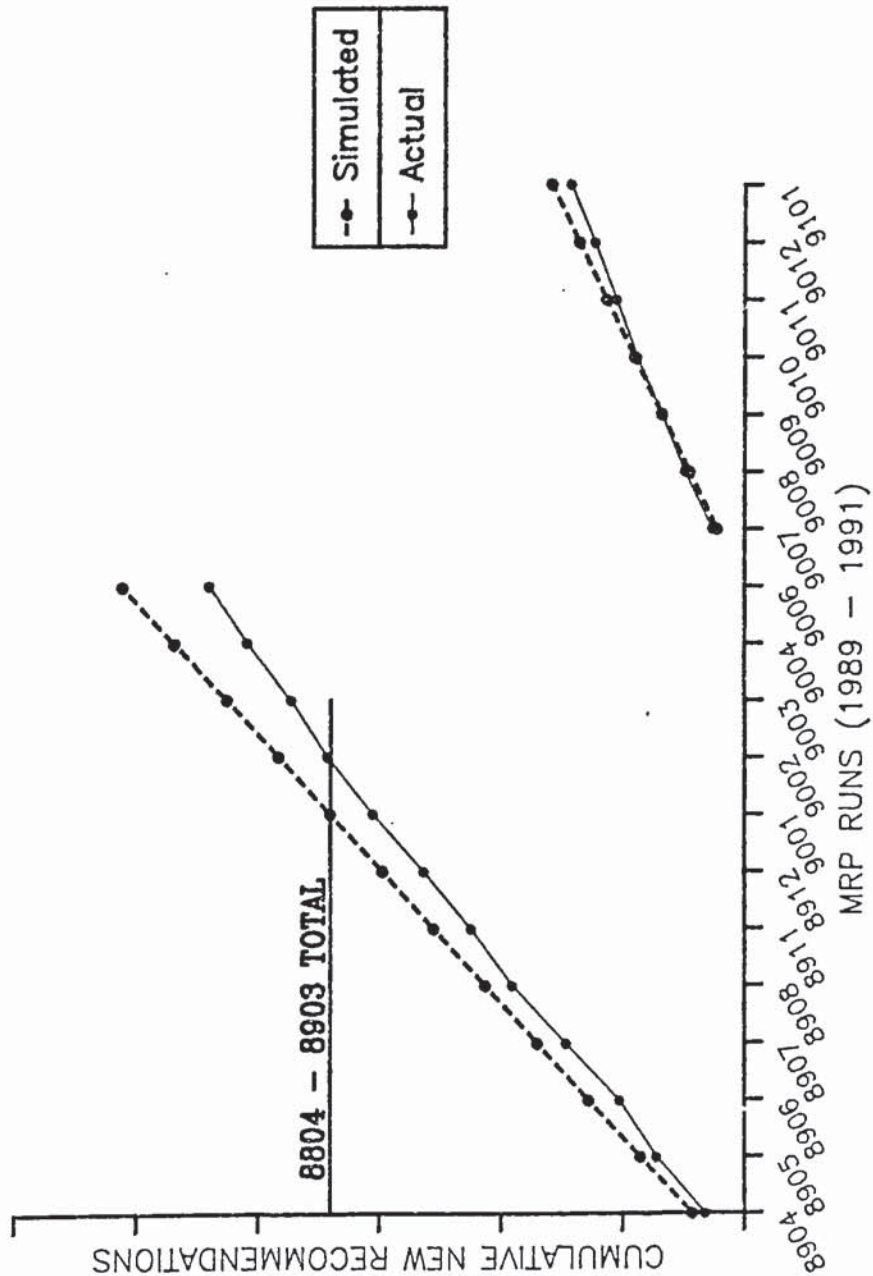
The MRP system is run once a month at IBM and each cycle is referred to by the year and month (YYMM). For example, 8903 refers to the MRP cycle in March 1989. The rescheduling-out parameters were implemented for the 8903 MRP cycle and the rest were implemented for the 8904 cycle. The remainder of this chapter will discuss how the actual results achieved compared with the expected ones.

12.5.1 New Order Recommendations

Figure 12.1 shows the actual v the expected level of new order recommendations under the new ordering parameters. The ordering parameters were implemented for the 8904 MRP cycle. As can be seen from the results there is negligible difference between the planned and actual level over the first 6 or so months. This difference grew to just under 10 percent after 12 months (9003 cycle) and to just over 10 percent 15 months after the initial implementation (9006 cycle). The reasons for the deviation are explained below.

Statistically speaking we would have expected to see the actual level fluctuating about the simulated level. From the results it can be seen that the bias is one way and increasing as the months progressed. The reason for this is that after the implementation of the parameters, some more parts were progressively removed from the MRP and put onto JIT schedules. Naturally it has, as might be expected, resulted in slightly lower MRP recommendations. Another factor contributing to the reduction in the actual number of order recommendations is that in 9002 the plant experienced severe production problems on one of the products which resulted in a production stoppage. Consequently, inventory built up and as a result (refer to Figure 12.10), the system, as designed, acted by reducing the number of new orders for the parts that were in surplus.

**SIMULATED V ACTUAL NEW RECOMMENDATIONS
(SIMULATED USING 8902 MRP DATA)**



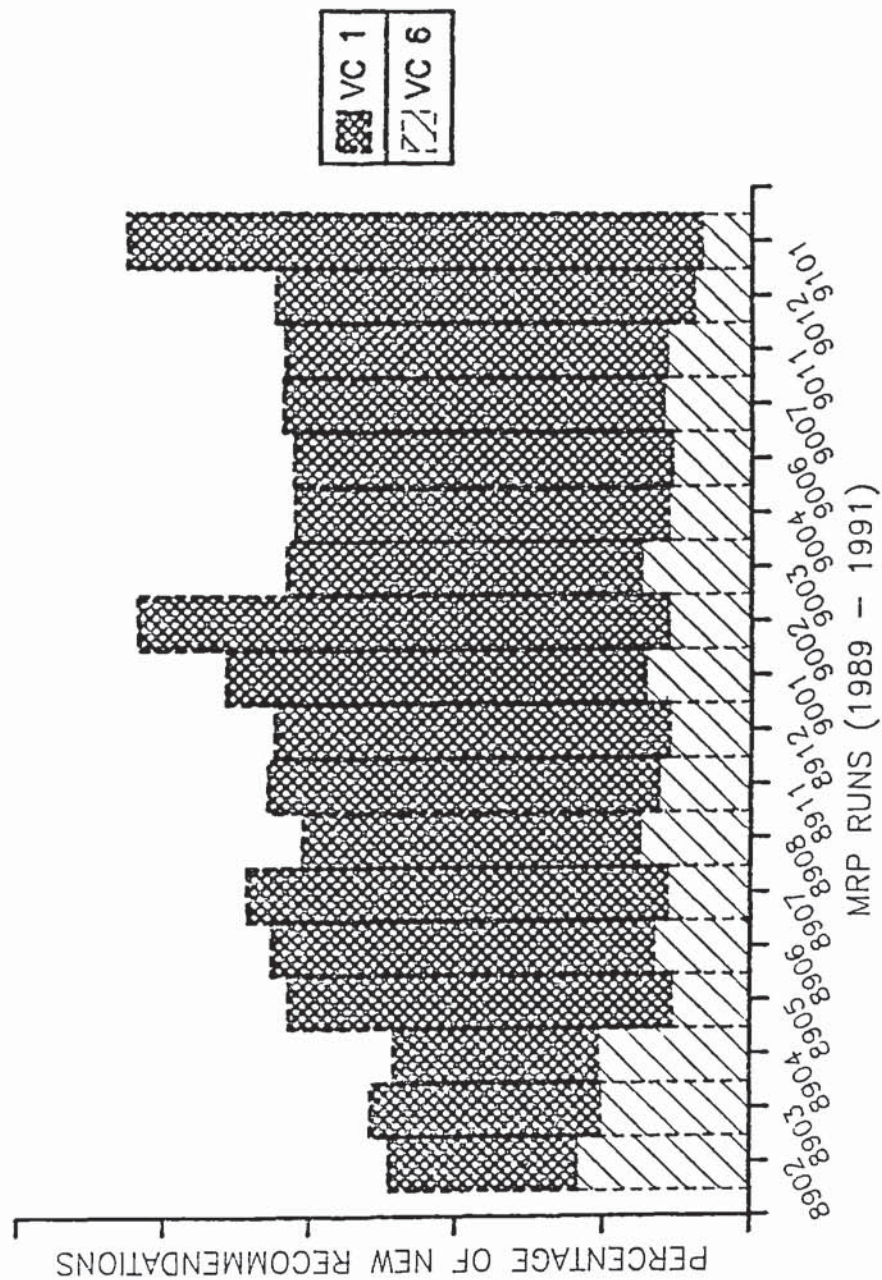
Another significant change in the process occurred in 9007. In 9007 all the inter-plant parts were put under a new JIT schedule. Under this process (called EIP - Enterprise Interplant Process), the delivery pattern is calculated by the MRP ordering parameters but the purchase orders are replaced by schedules. (The advantage of schedules is that changes can be automatically implemented without having to negotiate a formal contract as in the case of the traditional purchase orders. The benefits of purchasing schedules were discussed in chapter 2 and 7). The second set of lines shows the expected and the actual performance of the remaining MRP controlled parts after the process was implemented.

Notice, that the new expected rate is lower than the previous rate because obviously now there are fewer part numbers under the traditional MRP control.

12.5.2 Workload Transfer

One of the benefits of the ordering strategy (discussed in chapter 7) was that order recommendations should be increased in the higher value class and reduced in the lower value classes to achieve a better inventory leverage. This transfer is indicated by the step change in Figure 12.2. which shows the percentage of value class 1 and 6 order recommendations. Only the extreme value classes have been shown here because as we would expect, this is where transfer is the most significant. In the middle ranges the transfer is gradual and insignificant and is therefore not shown for clarity.

MIGRATION OF NEW RECOMMENDATIONS



12.5.3 Reschedule-Out Recommendations

Figure 12.3 shows the actual v the expected level of reschedule-outs under the new reschedule dampening parameters. As can be seen from the results there is negligible difference between the planned and the actual level.

One may argue that the actual level should be slightly lower than the simulated level because as noted earlier, some parts were put under JIT schedules over the first period. However, the difference is insignificant because the parts initially removed from MRP are the ones that are highly stable. As discussed in chapter 2, this is one of the conditions that must be fulfilled before a part number is put under a JIT purchasing schedule.

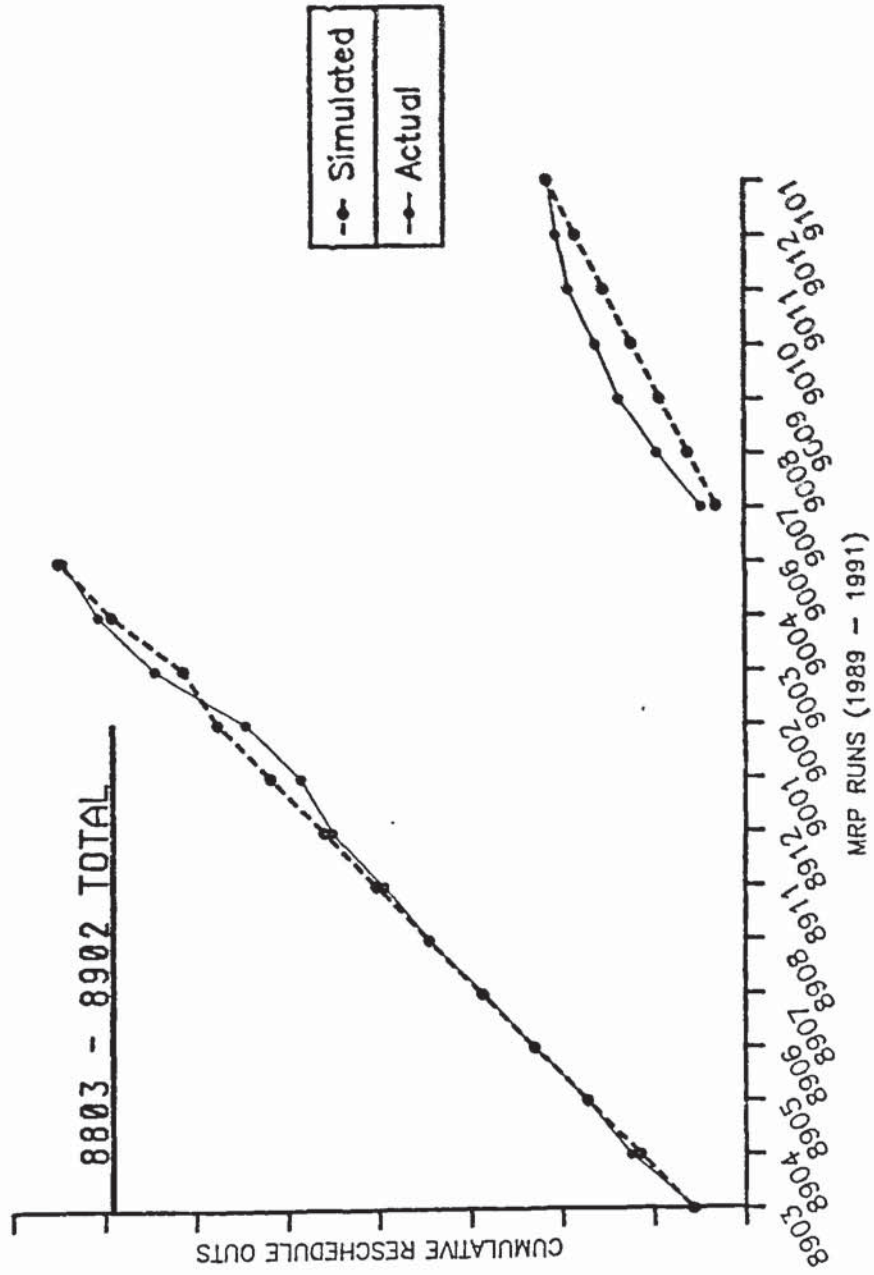
The second set of lines shows the actual and the expected volume of reschedules after the new EIP process, discussed above, was implemented. The actual level is slightly higher than the simulated one over the first few months after implementation because there were further production stops - refer to Figure 12.10. The system attempted to reduce excess inventory by rescheduling-out orders. Also notice that the new rescheduling rate after implementing the EIP process is lower than the previous case because fewer parts are now under MRP control.

The dampening parameters were implemented to achieve the effect discussed in chapter 7 i.e. the lower value class orders should be more heavily dampened than the high value class items. Figure 12.4 shows the actual number of reschedule-outs by value class. The step decrease in the numbers occurs at the point when the new dampening parameters were implemented. Notice that value class 6 reschedules have almost disappeared as was designed by the parameters. On the other hand, value class 1 is the most reactive to changes (again as was designed). The system gradually becomes less sensitive from value class 1 to value class 6.

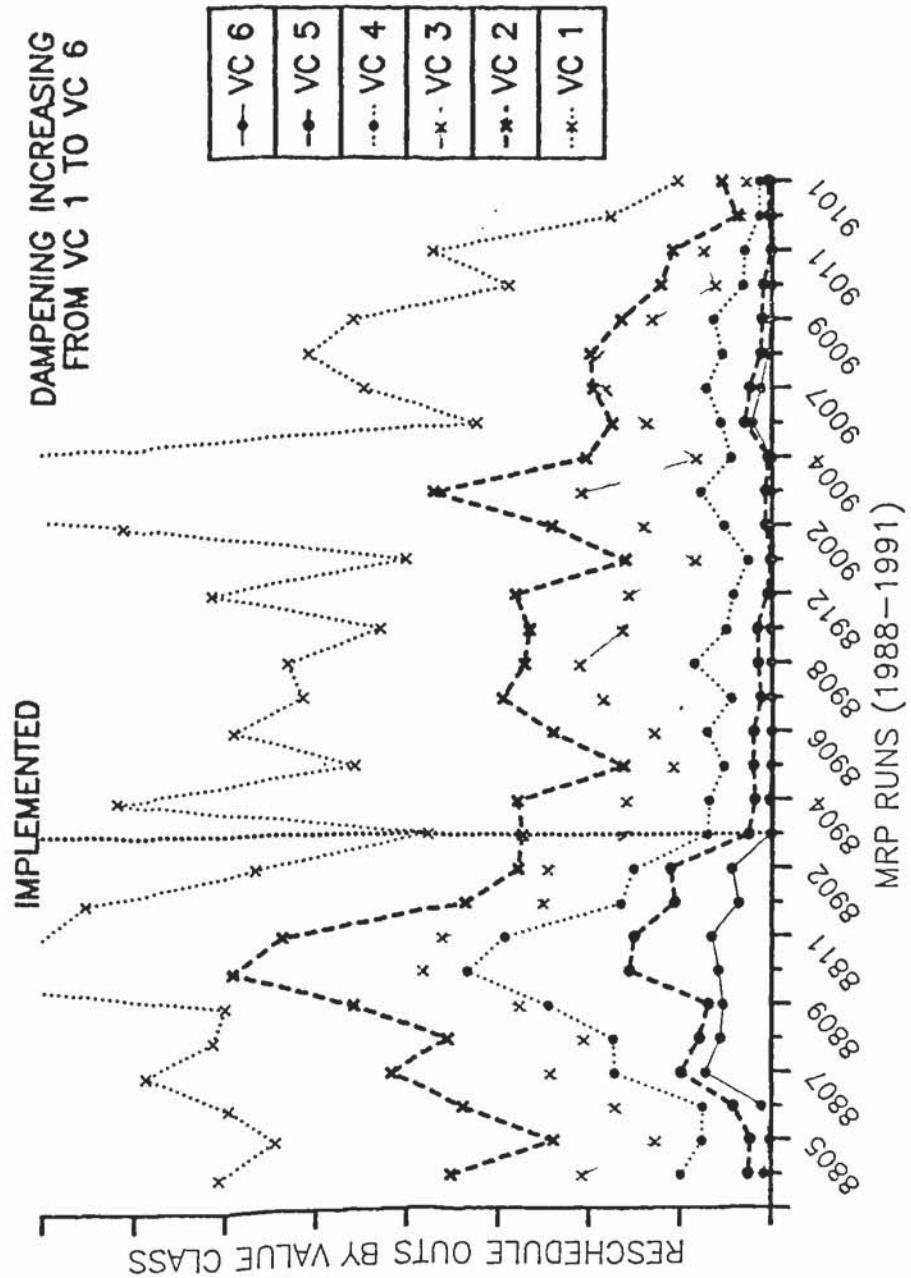
Notice that after 9007 the number of reschedules have gone down because of the EIP system discussed previously. Also note that where dampening is applied, the number of reschedules are fairly stable compared to before the parameters were implemented.

This is better seen in Figure 12.5 which shows the total number of reschedule-outs each cycle. Obviously there are still some fluctuations from cycle to cycle but the magnitude is much smaller. As was discussed in chapters 3 and 4, fluctuating levels of recommendations was also a problem with MRP. This new method of dampening not only reduces the number of trivial reschedules but it also greatly stabilizes the total number of reschedules generated.

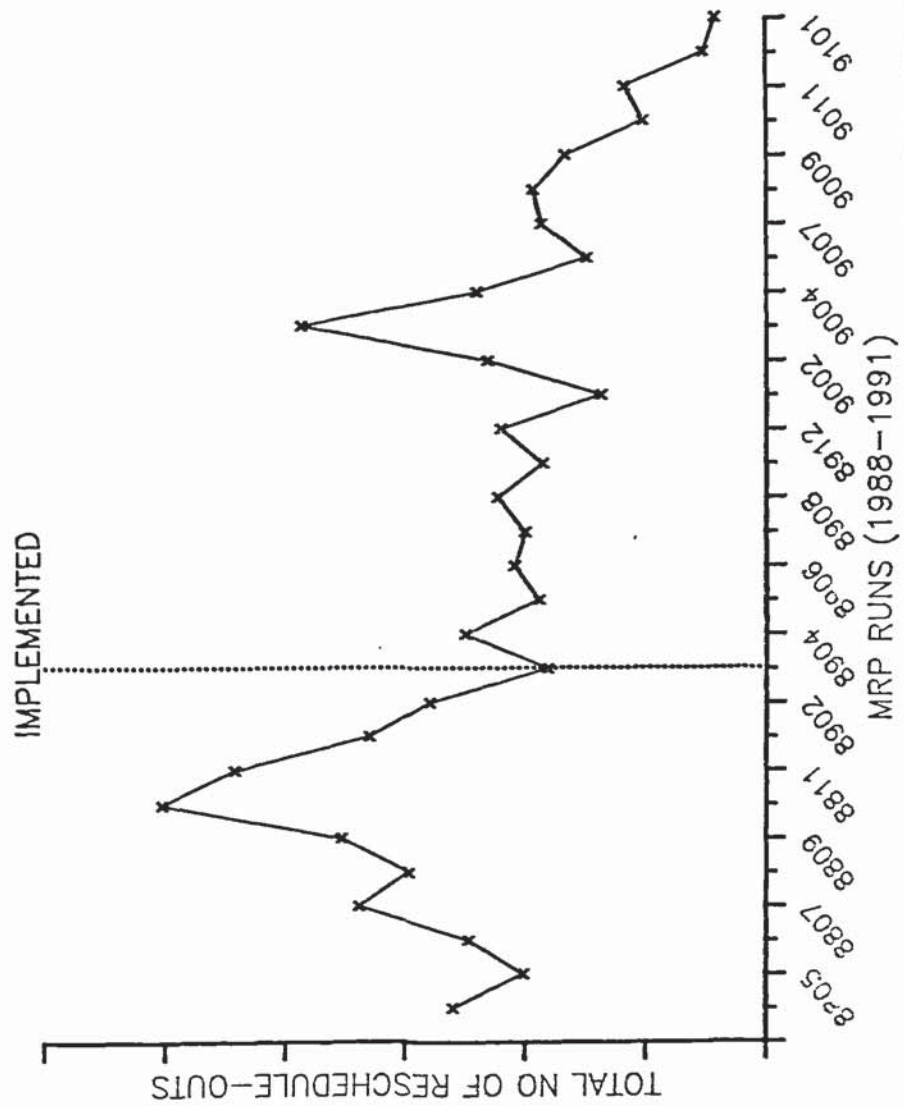
**SIMULATED V ACTUAL RESCHEDULE OUTFS
(SIMULATED USING 8902 MRP DATA)**



RESCHEDULE OUTS BY VALUE CLASS



ACTUAL NO OF RESCHEDULE-OUTS



12.5.4 Reschedule-In Recommendations

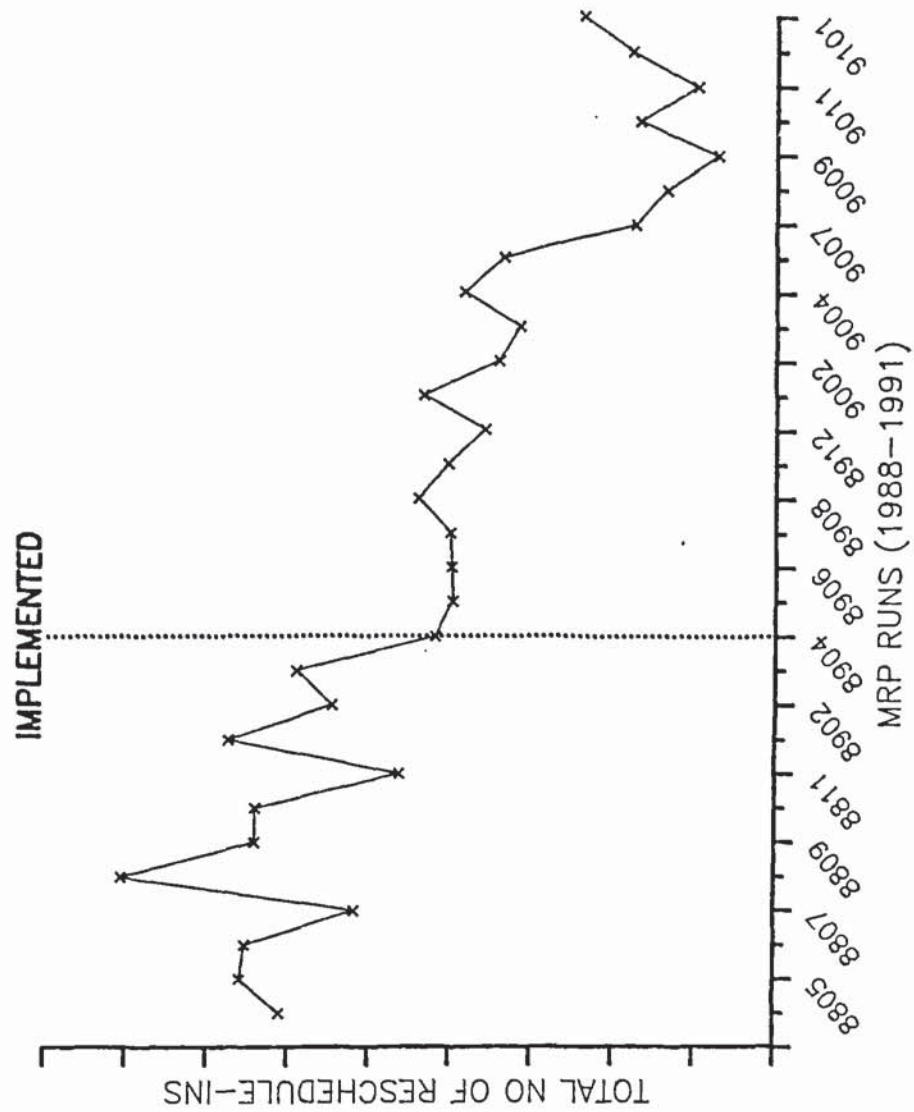
Figures 12.6 and 12.7 show the actual total number of reschedule-ins and the reschedules by value class respectively. The same points hold as in the case of reschedule-outs above. The point that the number of reschedules are now much lower and much more stable than previously is brought out more clearly in Figure 12.6.

12.5.5 Cancellations Recommendations

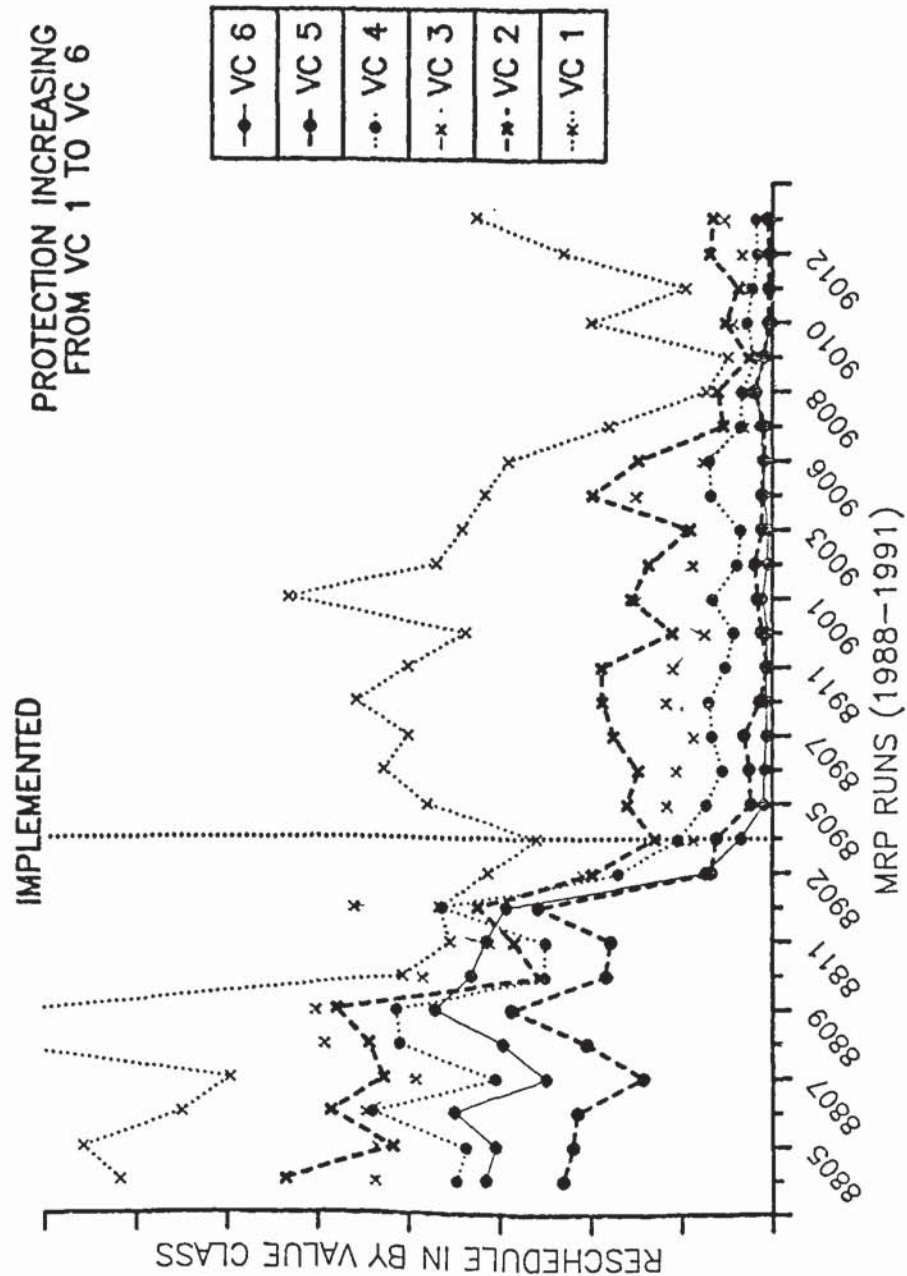
Figure 12.8 shows the actual total number of cancellations. The number of cancellations are significantly lower than was the case before the new parameters were implemented. The reason for the reduced number of cancellations is that with the ordering strategy used, there is a lot less inventory on order at any point in time and consequently there is a lower incidence of cancellations.

As was discussed in chapter 10, cancellation of orders incurs larger penalties than reschedules. Therefore the significance of reducing the number of cancellations is that a lot less expense is incurred by the buying department in purchasing parts.

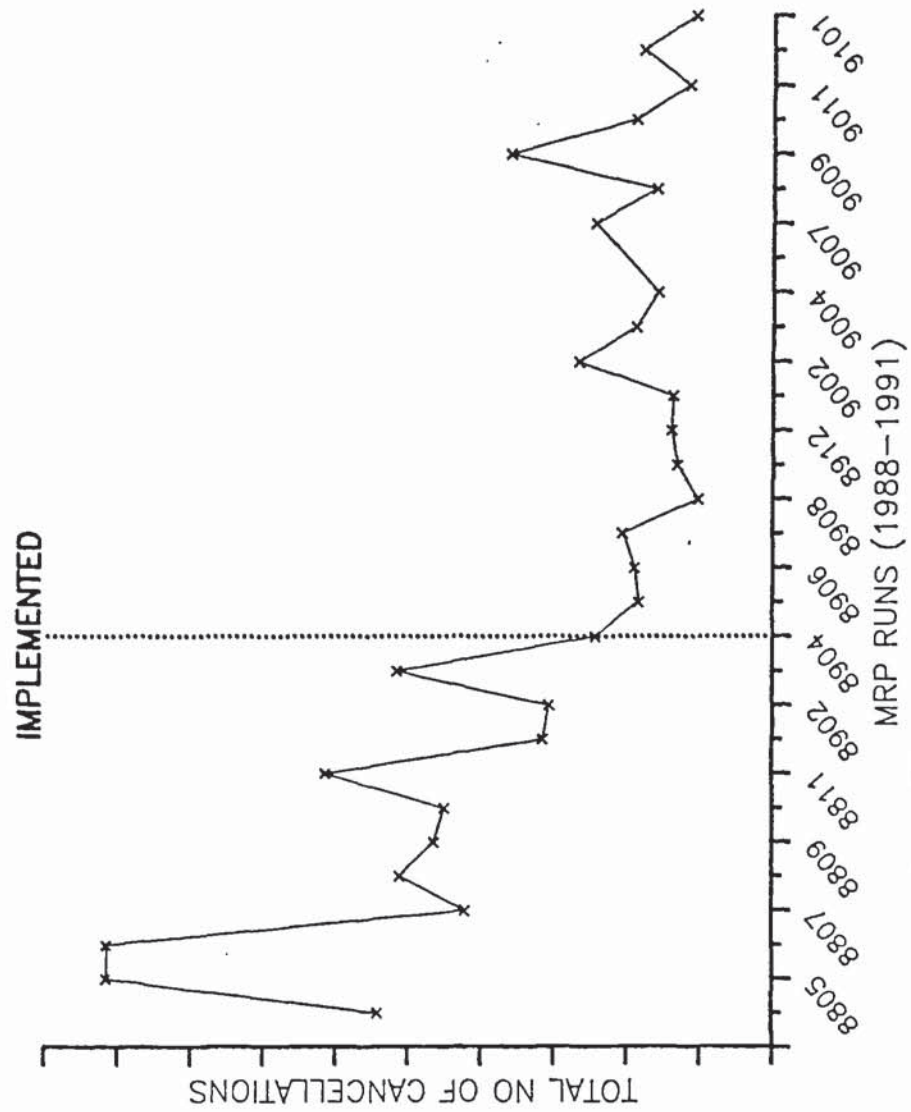
ACTUAL NO OF RESCHEDULE-INS



RESCHEDULE INS BY VALUE CLASS



ACTUAL NO OF CANCELLATIONS



12.5.6 MRP Compliance

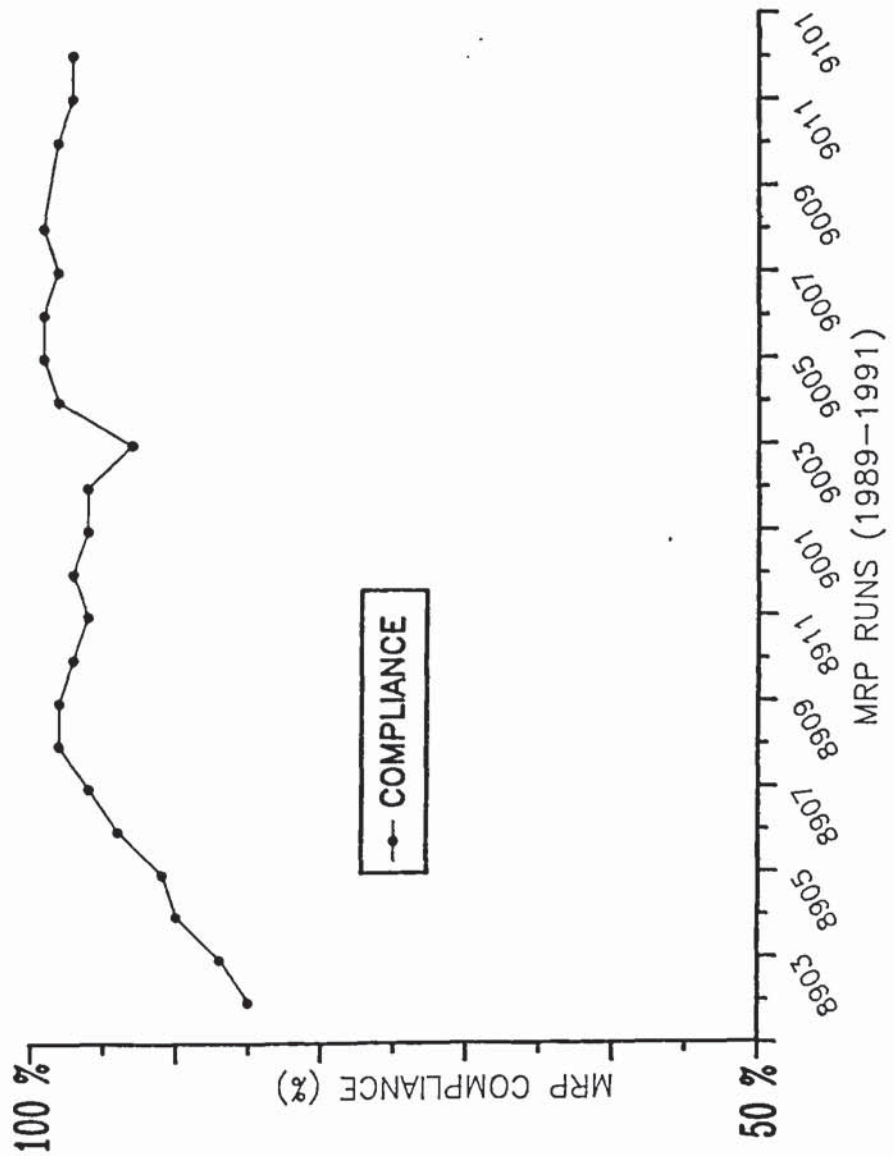
One of the objectives of the strategy is to gain inventory leverage by transferring workload from the low to the high value class according to the Pareto principle. If the ordering and rescheduling parameters are set to achieve this balance then it is likely that more of the MRP recommendations will be accepted by the analyzers and buyers without manual alterations, thus achieving the objective of an intervention free process.

The combined effect of the ordering and rescheduling parameters have pushed the compliance up by over 15 percent at IBM Havant, which is better than could have been imagined. Figure 12.9 shows the actual compliance. It has steadily improved since the parameters were implemented. In fact it is now consistently around the 98 percent mark as can be seen from the figure. Indeed Havant is now the best plant, of the 14 IBM manufacturing plants within Europe, in terms of meeting its 'intervention free' status.

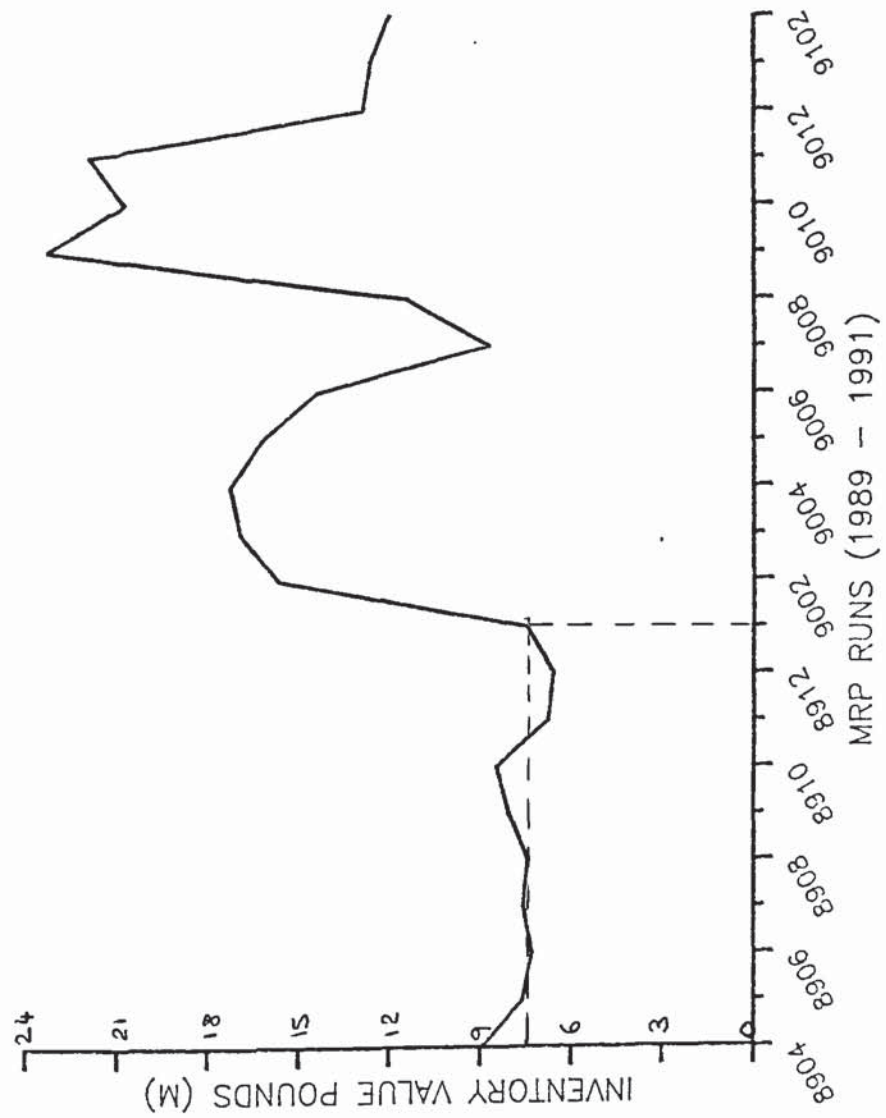
12.5.7 Inventory

As a result of implementing the proposed parameters, it was expected that the inventory would reduce by at least 1.5 million pounds. Figure 12.10 shows the total wall-to-wall inventory. From the figure, it is clear that the average inventory over the first 8 months has been reduced from an initial high in 8904. Prior to 8904 there were no reliable figures, but interviews with the inventory staff at IBM does confirm that the inventory levels were much higher and indeed highly fluctuating prior to 8904. Also as can be seen from the figure, not only has the inventory gone down over the first year but it is also fairly stable. This was one of the predicted benefits of using the new ordering and rescheduling parameters. Reducing the volatility of the inventory and workload levels was one of the objectives of implementing the proposed methodology.

MRP COMPLIANCE



TOTAL WALL-TO-WALL INVENTORY



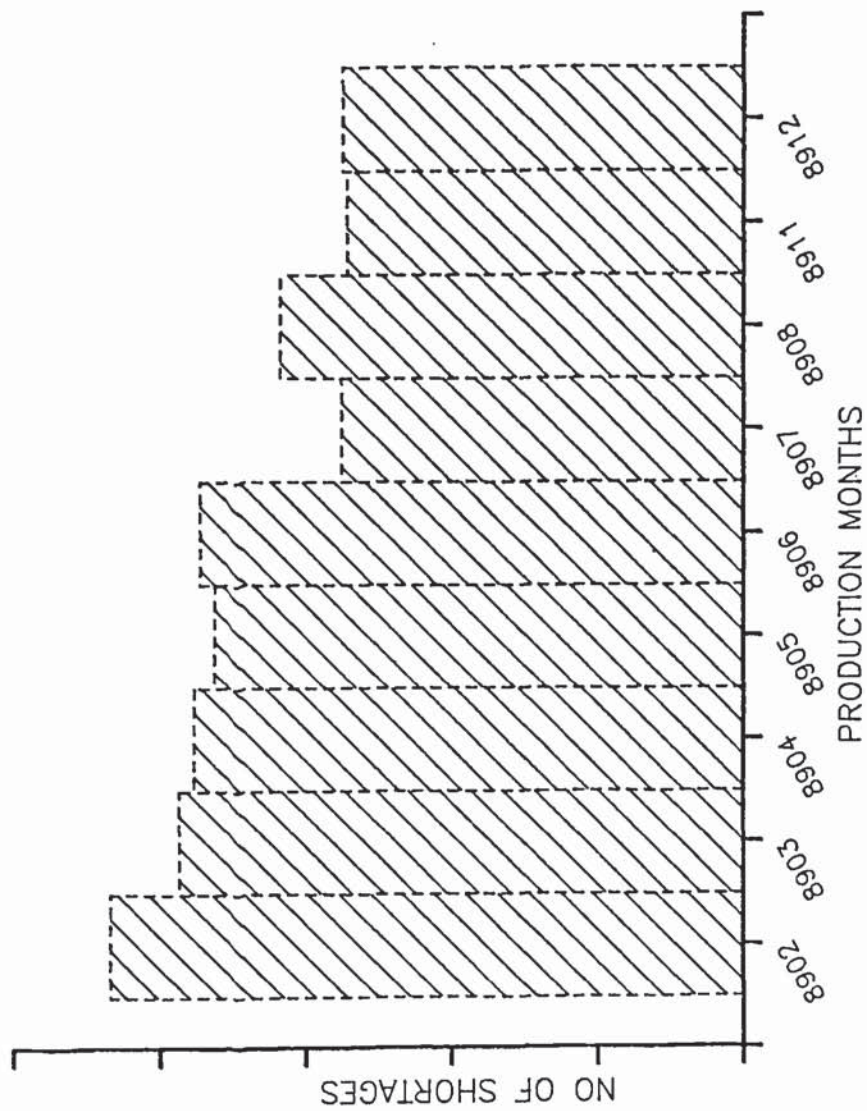
In 9002, all shipping of a particular disk file was stopped due to a suspected quality problem. Consequently the inventory level rose sharply. Further, the inventory value of the finished units is much higher than the individual components. Generally, IBM Havant does not have any finished goods inventory, so under normal conditions, all the inventory is that of components. As a remedial action, all the files had to be tested before shipping. With the large volumes of disk files involved, the backlog of files took about 5 months to clear, as can be seen in figure 12.10.

A similar crisis occurred in 9009, but this time with one of the telecommunication product. These products are of much higher value, consequently a larger increase in the inventory level was seen. These are obviously exceptional circumstances which cannot be averted by parameter management. There are many other factors which affect wall-to-wall inventory figures which made it difficult to isolate the effect of parameter changes. However, as can be seen from the figure, the inventory did not rise uncontrollably and the system managed the situation by rescheduling-out orders and not releasing any more new orders (as was discussed earlier). If the parameters had not been set correctly then the pipeline inventory would have poured in taking the inventory through the roof.

12.5.8 Shortages

One of the traditional arguments levelled against increasing the number of deliveries (or new order recommendations) is that it will increase the probability of shortages whereas the author argued that it would not be the case. This was discussed in chapter 11. Figure 12.11 shows how the theories have fared. Type 'A' shortages are system generated warnings which indicate that there will be a potential production shortage unless expediting action is initiated, i.e. critical shortages. As is seen, the shortage warnings have not increased despite an increase in the number of delivery recommendations, justifying the author's assumptions. In fact they have gone down.

TYPE 'A' SHORTAGES



12.6 Discussions

All the results shown are part of the key health indicators at IBM Havant. They are monitored and analysed each MRP cycle by an independent group (called the EMLS group). It is clear from the results that the simulations are fairly accurate and that the parameters achieved the desired effects. Apart from achieving a reduction in inventory and system nervousness, the parameters have indeed stabilised the volume of MRP recommendations and inventory levels, i.e. the levels do not fluctuate widely each cycle. It is also clear from the results that the system is fairly stable under typical conditions. When there is an exceptional situation the parameters bring the system under control fairly quickly.

From the results it is obvious that the users now have much more control over the system and can tune it exactly to meet the business requirements using the model/methodology. The model/methodology has proved that it can not only control the system but can also predict that performance fairly accurately.

From the author's experience, it is recommended that the model is run prior to implementing any major schedule changes in the system. In any case the model should be run at least once a year. At IBM the model is now part of the formal business planning process. The model is run prior to formalising the inventory and expense plans to ensure that the plans are achievable.

This model was first jointly published by the author in the "The British Production and Inventory Control Society - Control" journal. The model has now also been implemented at several other IBM plants and at least two other U.K companies with similar results.

Chapter 13

Conclusions

13.1 Modern Environment

Rising manufacturing costs, combined with increased international competition (largely spurred from the East) and a shift in market conditions towards higher product diversity and availability, has resulted in an increased focus on the need for effective manufacturing planning and control. To remain competitive, organisations are exploring new ways to reduce inventory and production costs while increasing worker productivity and quality. Towards this end, many organisations have abandoned their traditional reorder point types of systems and turned to more formal procedures and practices to improve their production planning and control capability. This trend is evident in the explosive growth of MRP systems over the last two decades. More recently, companies are adopting the Japanese manufacturing techniques and Just-In-Time based systems.

13.2 Research Findings

In chapter 2 it was discussed that while traditional reorder point systems such as Two-Bin were simple to operate and control, they however resulted in excessive and unbalanced inventory. Many companies have now replaced them with MRP systems. It was shown that despite the huge investments in MRP systems, organisations are not achieving the level of performance they desire. MRP systems are not operating successfully. Users have complained of "nervous" systems with volumes of order recommendations oscillating widely each time the MRP is run. Inventory levels are generally still high and unbalanced - the very reasons MRP was brought in. These have resulted in a low level of user confidence and over 80 percent of the systems can be classified as failures. From chapters 3 and 4 it emerged that the key factors undermining MRP systems are:

- a. poor choice of operational policies and parameters

- b. lack of guidance or tools to set those parameters
- c. setting parameters by trial-and-error methods without actually knowing their effects on system performance in advance
- d. probably more significantly, the parameters are rarely (if indeed ever) reviewed in light of the changing business environment.

More recently JIT has received much attention. Clearly, JIT has many benefits which enhance inventory performance and costs. However, those who have introduced JIT systems have found that JIT does not provide the whole solution either, because JIT (small quantity, high frequency) deliveries dramatically increase order and delivery workloads. JIT deliveries are not economical for smaller volume, low unit cost parts. For this reason it is typical to find JIT efforts directed at some of the larger volume, high unit cost parts.

It has been shown that for effective materials planning and control, an integrated strategy should be developed to migrate towards JIT purchasing concepts from the existing MRP systems. However, as was discussed in chapter 2, there exists a potential for mismatch and conflict between these systems. Indeed, indiscriminate use of JIT deliveries can raise material acquisition costs through increased traffic and schedule/order workload management.

Clearly, JIT, MRP, and ROP systems all have some limitations and could not succeed individually. The way forward is to combine these three approaches to form a total solution. This dissertation demonstrates the potential for integration between JIT, MRP, and Two-Bin at IBM Havant. Of the three systems, it was considered that successful control and management of MRP was a prerequisite to, and the key for the overall success of the whole materials planning and control system. Furthermore, it was considered that achieving an 'intervention free' MRP system was an essential step toward JIT. It frees up valuable resources to concentrate on developing JIT and Two-Bin supplies progressively. Key elements in the solution were the choice and setting of the ordering, rescheduling, and safety policies and parameters in MRP. Chapters 3 and 4 discussed the roles of these policies and parameters in MRP and in chapters 5 and 6 the problems in setting them were evaluated.

Significant in the findings was that the traditional economic order quantity (EOQ) and rescheduling models were not useful within a JIT environment because of their singular concern for minimising short-term ordering and inventory costs; which in themselves were found to be indeterminable in practice. Another criticism was the fact that while optimisation models minimised the total costs at the micro level, i.e. at part number level, there is frequently an increase at the macro level, i.e. when all the parts are considered together. Moreover, it was found that model developers have typically assumed these costs to be given rather than examining ways in which these parameters could be changed/simplified. What emerged provided the basis for a critical re-evaluation and simplification of the whole MRP parameter setting and management process.

13.3 Mixed Ordering Strategy

The benefits of JIT purchasing concepts are undeniable. However, although smaller more frequent deliveries reduce costs associated with holding inventory, they do inevitably increase the administrative and transportation workload to a point where JIT deliveries become uneconomical. Another significant factor was the conflict between flexibility and stability. JIT gives flexibility, but to operate JIT requires stability. These were shown to be two incompatible objectives. To achieve a balance between stability and flexibility, and a balance between inventory and workload, a mixed ordering strategy was developed. This was discussed in chapter 7.

The concept is based on the Pareto principle which is both simple to understand and implement. It is a very effective system from a management point of view because it separates the 'important' few from the 'trivial many'. The important few (the 'A' class items) are managed under personal control or JIT purchasing schedules, while at the other extreme, the very low annual usage value items, (the 'C' class items), such as nuts, bolts, washers, etc...are controlled using a Kanban or Two-Bin approach.

The remaining items are under MRP control. Within MRP, the general strategy is to manage and control items by similar Pareto groupings, i.e according to their annual

usage value - higher annual usage value items are controlled more tightly and ordered/delivered more frequently than lower annual usage ones. Moreover, to stabilise and reduce the administrative workload caused by rescheduling notices, the lower annual usage value items are more heavily dampened than the higher ones, i.e. the low value class items are made less sensitive to changes. With this strategy, the increase in the administrative workload, resulting from more frequent delivery, is countered by the reduction in the rescheduling workload; the net effect of which is to reduce the total workload in purchasing.

13.4 MRP Control Policies

Having developed the broad control strategy, chapters 8 to 11 went on to develop models to maintain the fine balance between sensitivity (flexibility) and inventory (stability). The models also enable the user to achieve an 'intervention free' MRP system to facilitate migration towards JIT concepts discussed earlier. The objectives of the models were to meet the conflicting requirements of:

- a. reducing inventory
- b. stabilising MRP
- c. improving service levels
- d. facilitating the development of true JIT and Two-Bin supplies.

Although the ordering and rescheduling models were discussed separately, they can, however, be thought of as a single integrated model. Controllable parameters within this model are ordering, rescheduling and safety policies. The setting of these parameters directly affected the number of orders raised/received and rescheduled (i.e. purchasing workload) and inventory levels.

13.5 Models

Significant in the modelling approach was the assumption that the parameters of the system are no longer fixed or given, but rather, the user has control over them and can manipulate them, not only to meet, but to also test, a given business plan. This philosophy has changed the goal of the parameters from that of optimising the given system, to a more proactive attempt to manage and change the system where necessary. It was demonstrated that managers and researchers need to address the

dynamics and operation of the whole system and not merely a total cost function as specified by some mathematical EOQ calculations. The important point drawn was the concept that a trade-off exists between inventory, workload, and stability.

The actual models are based on the idea of marginal costing or non-linear variable costing, not explicit or absolute costs, i.e. costs are fixed in the short term and only become significant when the workload created a need to call on additional new resources, either in new systems or manpower. Initial assumptions made are that the existing resources: buyer staff, receiving staff, store size etc., are not to be increased.

The principles of the models and the methodologies involved are simple enough. However, to be of practical value they were developed as computer iteration models. Operationally, the models are used to compare existing performance with target performance and calculate the relative or marginal difference. Using the models, a series of different parameters are tested and its impact on inventory and order workload calculated. (The ordering model gives the inventory v new order workload performance; the rescheduling model gives the inventory v rescheduling workload). The balance between inventory and workload is plotted as 'exchange curves'. This gives management an opportunity to make balanced decisions to move along the exchange curve in a controlled way. Initially, it allows a plant to determine whether or not it is on the exchange curve and if not to make changes to reach the curve. Once a particular balance is chosen, the models provide the appropriate parameters to achieve the plan.

The ordering model provides:

- a. No of groups
- b. Value class limits
- c. Order cycles
- d. Ordering cost/inventory holding rate

The rescheduling model provides:

- a. Dampening days
- b. Protective schedule

The elements in the models are:

- a. a modified EOQ formula (modified for MRP and marginal costing)
- b. an exchange curve showing the relationship between inventory and number of orders/reschedules
- c. coverage analysis method which groups parts based on the common order cycles and forecasted annual usage value
- d. dampening parameters to suppress reschedules
- e. protective schedules (safety lead times) to counter the effects of not rescheduling

13.6 Results

The models were used to implement a coherent set of parameters at IBM Havant. Using these models, significant improvements in inventory and system stability were achieved while, at the same time, simplifying the role of MRP and improving the performance of the whole production planning and control system. The actual performance of the system, over a period of more than two years after the new parameters were implemented was compared against the expected in chapter 12. The results speak for the success of the models and their assumptions.

A critical success factor in these models was the establishment of the models' credibility. This was established through simulating the system's performance against historical data and training management and users of the concepts involved. IBM would not have considered the implementation of the models if users were not convinced that they could work.

13.7 Suggestions For Future Systems and Research

MRP is a tool to increase efficiency, sometimes dramatically, if used correctly. However, MRP has not lived up to these expectations. On the other hand, JIT has been used as an alternative system by many companies with similar disappointing results. Some have argued that MRP and JIT are alternative approaches, while others have argued that JIT is a subset of MRP or that MRP is a subset of JIT. As is evident from this dissertation, it is neither. MRP and JIT are complementary and, if worked together, they will yield much better results than trying to work them separately.

These findings are significant for system developers and suppliers. They have traditionally promoted complex 'CAPM' (Computer Aided Production Management) solutions to improve manufacturing efficiency. While computers are an essential part of good manufacturing management, this research has shown that people must still make the decisions. Therefore the objective of any new methodologies and systems must be to provide a set of tools to help management make those decisions effectively. In particular, users will benefit from conceptually clear and simple techniques which are capable of integrating to meet the ever changing business needs. This is essential because to remain competitive in the nineties, manufacturing companies will continue to seek to change their planning and control practices so as to improve their competitiveness.

It is suggested that in the search for new methodologies for manufacturing control systems, certain criteria be developed. For instance, it is suggested that researchers look to develop methods which:

- a. exploit the ever-increasing capability of computers
- b. support managerial decision making instead of methods which merely report on or account for it
- c. facilitate the insertion of new knowledge as it is discovered
- d. are simple, yet not simple minded

Within this context, research is required to see whether the model developed here to control bought-out inventory can be extended (be it in a modified form) to control manufacturing which is dogged with similar problems tackled in this research.

References

- Aggarwal, V., 'A Closed-Form Approach for Multi-Item Inventory Grouping', *Naval Research Logistic Quarterly*, Vol. 30, pp. 471-485, 1983.
- Aggarwal, V., 'Modeling of Distributions by Value for Multi-Item Inventory', *IIE Transactions*, Vol. 16, No. 1, pp. 90-98, 1984.
- Aggarwal, S.C., 'MRP, JIT, OPT, FMS?', *Harvard Business Review*, September-October 1985, pp. 8-16.
- Aucamp, D.C., 'A Caveat on Using Setup Costs in Lot-Sizing', *Production and Inventory Management*, 4th quarter, pp.11-14, 1984.
- Bahl, H.C., and Zionts, S., 'Lot Sizing as a Fixed-Charge Problem', *Production and Inventory Management*, Vol. 27, No 1, pp. 1-10, 1986.
- Baker, K.R., 'An Experimental Study of the Effectiveness of Rolling Schedules in Production Planning', *Decision Science*, Vol. 8, pp. 19-27, 1977.
- Blackburn, J.D., Kropp, D.H., Millen R.A., 'Nervousness: Causes and Cures', *Engineering Costs and Production Economics*, pp. 141- 146, 1985.
- Blackburn, J.D. and Millen, R.A., 'Improved Heuristics for Multi-stage Requirements Planning Systems', *Management Science*, Vol. 28, pp.44-56, 1982.
- Campbell, W.L., 'Scheduling is Not the Problem', *Production and Inventory Managemt*, 2nd Quarter, pp. 19-26, 1971.
- Carlson, R.C., Jucker, J.V., and Kropp, D.H., 'Less nervous MRP systems: A dynamic lot sizing approach', *Management science*, Vol. 25, No 8, pp. 754-761, 1979.
- Chakravarty, A.K., 'Inventory Grouping For Joint Replishment', *Engineering Costs and Production Economics*, pp. 19-24, 1982.
- Chand, S., 'Dynamic Lot Sizing in a Rolling Horizon Environment' Working Paper, Purdue University, 1980.
- Clark, S.R., 'Aspects of the Design and Control of Manufacturing Systems Subject to Demand Uncertainty', PhD Thesis, The University of Aston in Birmingham, March 1988.
- Corke, D., *Production Control & Engineering*, Published by Arnold, pp. 173-199, 1987.
- Crouch, R.B, and Oglesby, S., 'Optimization of a Few Lot Sizes to Cover a Range of Requirements', *J.Opl Res.Soc.* Vol.29, No.9, p 897-904, 1978.
- Davies. E.W., 'A Look at the Use of Production-Inventory Techniques: Past and Present', *Production and Inventory Management*, 4th quarter, pp. 1-19, 1975.
- Dear, A., 'Working Towards Just-In-Time', published by Kogan Page, 1988.
- De Bodt, M.A. and Van Wassenhove, L.N., 'Lot Sizing and Safety Stock Decisions in an MRP Systems with Demand Uncertainty', *Engineering Costs and Production Economics*, pp. 67-75, 1982.

- De Bodt, M.A. and Van Wassenhove, L.N., 'Cost Increases Due to Demand Uncertainty in MRP Lot Sizing', *Decision Sciences*, Vol. 14, pp. 345-362, 1983.
- De Bodt, M.A. and Van Wassenhove, L.N., 'Lot Sizing and Safety Stocks in MRP: A Case Study', *Production and Inventory Management*, pp. 1-16, 1983.
- De Matteis, J.J. and Mendoza, A.G., 'An Economic Lot Sizing Technique', *IBM Systems Journal*, Vol. 7, pp. 30-46, 1968.
- Donaldson, W.A., 'Grouping of Inventory Items by Review Period', *J.Opl Res.Soc.* Vol.32, No.12, pp. 1075-1076, 1981.
- Fintech, 'UK: Academe Offers World-Class Manufacturing', *Financial Times Business Information*, pp. 134/2-134/4, 1989.
- Flores, B.E., and Whybark, D.C., 'Implementing Multiple Criteria ABC Analysis', *Journal of Operational Management*, Vol. 7, No 1&2, pp. 79-85, 1987.
- Fox, R.E., 'OPT vs. MRP, Throughware vs. Software', *Inventories and Production Magazine*, Nov 1983.
- Freeland, J.R., and Colley, J.L., 'A Simple Heuristic Method for Lot Sizing in a Time-Phased Reorder System', *Production and Inventory Management*, Vol. 23, No 1, pp. 14-22, 1982.
- Goldratt, E.M., 'The Unbalanced Plant', *Proceedings of APICS Annual Conference*, pp36-51, 1981.
- Gorham, T., 'Dynamic Order Quantities', *Production and Inventory Management*, Vol. 10, pp. 75-81, 1968.
- Haddock, J. and Hubicki, 'Which Lot-Sizing Techniques are used in Material Requirements Planning Systems', *Production and Inventory Management*, Vol. 30, 3rd quarter, pp. 53-56, 1989.
- Hall, R.W., 'Driving the Productivity Machine: Production Planning and Control in Japan', *American Production and Inventory Control Society*, Falls Church, 1981.
- Harris, F.W., 'Operations and Costs', *Factory Management Science*, A.W Shaw Co, Chicago, 1975.
- Ho, C.J., 'Evaluating the impact of operating Environments on MRP systems nervousness', *International Journal of Production Research*, Vol. 27, No. 7 pp. 1115-1135, 1989.
- Ho, C.J.; Carter, P.J.; Melnyk, S.A.; Narasimhan, R., 'Quantity Versus Timing Change in Open Order: A Critical Evaluation', *Production and Inventory*, 1st Quarter, pp. 122-136, 1986.
- Hsu, J.I., El-Najdawi, M.; 'The Effects of Demand Distribution on Optimal Safety Stock Determination', *Production Management & Control*, pp. 23-24, December 1988.
- Jacobs, F.R; Khumawala, B.M., 'A Simplified Procedure for Optimal Single-Level Lot Sizing', *American Production and Inventory Control Society*, 3rd quarter, pp. 39-43, 1987.
- Jones, B., 'Managing Critical Resources', *Proceedings of the 22nd European Technical Conference on Production and Inventory Control*, pp. 11-31, Nov 1987.
- Karni, R., 'Maximum Part-Period Gain: A Lot-sizing Procedure for Unconstrained and Constrained Requirements Planning' *Production and Inventory Management*, Vol. 22, No. 2, pp. 91-98, 1981.

Kropp, D.H., Carlson, R.C., Jucker, J.V., 'Use of Dynamic Lot-Sizing to Avoid Nervousness in Material Planning Systems', *Production and Inventory Management*, Vol. 20, 3rd quarter, pp. 49-57, 1979.

Kropp, D.H., Carlson, R.C., Jucker, J.V., 'Heuristic Lot-Sizing Approaches for Dealing with MRP System Nervousness', *Decision Science*, Vol. 14, pp. 156-169, 1983.

Lewis, C.D., *Scientific Inventory Control*, Published by Butterworth, 2nd edition, 1981.

Lowerre, W.M., 'Protective Schedules Smoothes Jittery MRP Plans: Buffer Forecast Error The Key', *Production and Inventory Management*, 1st quarter, pp. 1-21, 1985.

Mather, H., 'Reschedule the Reschedules You Just Rescheduled- A Way for MRP?', *Production and Inventory Management*, Vol. 20, 3rd quarter, pp. 60-79, 1977.

Mather, H.F., 'Dynamic Lot Sizing for MRP: Help or Hindrance ?', *Production and Inventory Management*, 2nd quarter, pp. 29-35, 1985.

Mc Claren, B.J., 'A Study of Multiple Level Lot Sizing Procedures For Materials Requirements Planning Systems', PhD Dissertation, Purdue University, 1977.

Minifie, J.R., Davies, R.A., 'Survey of MRP Nervousness Issues', *Production and Inventory Management*, 3rd quarter, pp. 111-119, 1986.

Minifie, J.R and Heard, E., 'On the Generalizability of MRP Simulation Results', *Engineering Costs and Production Economics*, Vol. 9, pp. 211-217, 1985.

Murdoch, J. (Ed), 'Coverage Analysis - A New Technique for Optimising the Stock Ordering Policy', *Proceeding of a one day conference held at Cranfield, U.K.*, 1965.

New, C., *Requirements Planning*, Essex, Gower Press, 1974.

New, C., 'Safety Stock for Requirements Planning', *Production and Inventory Management*, Vol. 30, pp. 50-62, 1975.

O'Grady, P.J., and Byrne, M.D., 'Lot Sizing in a Practical Manufacturing System', *Engineering Costs and Production Economics*, Vol.13, pp. 13-26, 1987.

Orlicky, J.A., *Material Requirements Planning - The New Way of Life in Prod and Inventory Management*, McGraw-Hill, 1975.

Orlicky, J.A., 'Rescheduling with Tomorrow's MRP System', *Prod and Inventory Management*, Vol. 17, No. 2, pp. 38-48, 1976.

Schonberger, R.J.; 'Japanese Manufacturing Techniques - Nine Hidden Lessons in Simplicity', published by 'The Free Press', 1982.

Shah.S.; Burcher,P.; Relph.G., 'The Setting of Ordering Parameters in a MRP/JIT Environment', Working Paper, Aston University, Oct 1989.

Shah.S.; Burcher,P.; Relph.G., 'Extending the Pareto Principle to MRP Controlled Parts and Regaining MRP Control', *BPICS*, April/May pp. 39-45, 1990.

Shah, S., 'Optimum Order Cycles In MRP Form a Geometric Progression', *International Journal of Operational & Production Management*, Vol. 11, No. 5, pp. 83-87, 1991.

- Silver, E.A and Meal, H.C., 'A Simple Modification of the EOQ for the Cost of a Varying Demand Rate', *Production and Inventory Management*, Vol. 9, pp. 52-64, 1968.
- Silver, E.A and Meal, H.C., 'A Heuristic for Selecting Lot-Sizing Quantities for the Case of Deterministic Time-Varying Demand Rate and Discrete Opportunities for Replenishment', *Production and Inventory Management*, Vol. 14, pp. 64-74, 1973.
- Silver, E.A. and Paterson, R., *Decision Systems for Inventory Management and Production Planning*, 2ed., Wiley, 1985.
- Steel, D.C., 'The Nervous MRP System: How to do Battle', *Production and Inventory Management*, Vol. 16, 2nd quarter, pp. 1-18, 1975.
- St John, R., 'The evils of lot sizing in MRP', *Production and Inventory Management*, 4th quarter, pp. 75-85, 1984.
- Sugimori, Y., Kusunoki, K., Cho, F., and Uchikawa, S., 'Toyota Production System and Kanban system: Materilization of Just-In- Time and Respect-For-Human System', *International Journal of Production Research*, pp. 553-564, Vol. 15, 1977.
- Thomas, A.B., *Stock Control in Manufacturing Industries*, Published by Gower Press, 2nd edition, 1980.
- Vickerby, S.K., 'International Sourcing: Implications for Just-In-Time Manufacturing', *Production and Inventory Management Journal*, 3rd quarter, pp. 66-71, 1989.
- Wagner, H.M., and Whitin, T., ' Dynamic version of the economic lot sizing model', *Management science*, Vol. 5, No 1, pp. 89-92, 1985.
- Wallace, T.F., 'MRPII: Making It Happen', The Oliver Wright Company, Essex Junction, VT, 1985.
- Waterlow, J.G, and Monniot, J.P., 'A Study of the State of the Art in Computer Aided Production Management in UK Industry'; SERC, 1986.
- Wemmerlov, U., 'Design factors in MRP systems: A limited survey', *Production and Inventory Management*, 4th quarter, pp. 15-35, 1979.
- Whiteside, D., and Arbose. J, 'Unsnaarlin Industrial Production: Why Top Management is Starting to Care', *International Management*, pp. 20-26, March 1984.
- Whybark, D.C., and Williams, J.G., 'Material Requirements Planning Under Uncertainty', *Decision Science*, Vol. 7, pp. 595-606, 1976.

Bibliography

Abernathy, W. J.; Clark, K. B.; Kantrow., 'The New Industrial Competition', *Havard Business Review*, Vol. 59, No. 5, pp. 68-81, 1981.

Anderson, J.C., Schroeder, R.G., Tupy, S.E., and White, E.M., 'Material Requirements Planning: A study of Implementation and Practice', *American Production and Inventory Society*, Falls Church, Virginia, USA, 1981.

Anton, C.J. and Malmborg, C.J., 'The integration of inventory Modeling and MRP Processing: A Case Study', *Production and Inventory Management*, 2nd quarter, pp. 79-89, 1985.

Bahl, H.C, and Ritzman, L.P., 'An Empirical Investigation of Different Strategies for Material Requirement Planning', *Journal of Operations Management*, Vol. 2, No. 3, pp. 67-79, 1983.

Bahl, H.C., Ritzman, L.P. and Gupta, J.N., 'Determining Lot Sizes and Resources Requirements: A review', *Operational research*, Vol. 35, No 3, pp. 329-345, 1987.

Baker, K.R., and Bertrand, J.W.M., 'An investigation of due date assignment rules with constrained tightness', *Journal of Operational Management*, Vol. 1, No 3, pp. 109-120, Feb 1981.

Biggs, J.R., Hanh, C.K., and Pinto, P.A., 'Performance of lot sizing rules in an MRP system with different operating conditions', *Academy of management review*, Vol. 5, pp. 89-96, Jan 1990.

Cerveny, R.P., and Clark, T.D., 'Conversations on why information systems fail-and what can be done about it', *Systems, Objectives, Solutions*, Vol. 1, pp. 149-154, 1981.

Chu, C.H., and Chu, Y.C., 'Computerised ABC Analysis: The Basis for Inventory Management', *Computers Ind Engng*, Vol. 13, Nos 1-4, P66-70, 1987.

Cooper, R.B and Zmud, R.W, 'Material Requirements Planning System Infusion', *Omega*, The International Journal of Management Science, Vol. 17, pp. 471-481, 1989.

Cox, L.F., and Clark, S.J., 'Problems in Implementing and operating a material resource planning information system', *Journal of management information systems*, Vol. 1, No 1, pp. 81- 101, 1984.

Dillon, R.E., 'Some Simple Steps to Inventory Reduction', *Production and Inventory Management*, 1st quarter 1990, Vol. 31, No 1, pp. 62-65.

Edwards, J.N., 'Integrating MRPII with JIT', *BPICS Control*, pp. 45-53, October/November 1988.

Fisher, 'Hoe to implement MRP successfully', *Production and Inventory Management*, 4th quarter, pp. 36-54, 1981.

Flores, B.E., and Whybark, D.C., 'Multiple Criteria ABC Analysis', 1986 *International Journal of Operational & Production Mamageent*, Vol. 6,(3), P38-56.

Gaither, N., 'A near optimal lot sizing model for Material Requirement Planning systems', *Production and Inventory Management*, Vol. 22, No 4, pp. 75-89, 1981.

Gaither, N., 'Using computer simulation to develop optimal inventory policies', *Simulation*, pp. 81-87, Sept 1982.

Gaither, N., 'An improved lot sizing model for MRP systems', *Production and Inventory control*, 3rd quarter, pp. 10-19, 1983.

Game, R., 'Manufacturing Strategies for the 90s', Proceedings of the 22nd European Technical Conference on Production and Inventory Control, pp. 3-11, Nov 1987.

Gerwin, D., 'Do's and Don'ts of computerised manufacturing', Harvard Business Review, pp. 107-116, March-April 1983.

Goldratt, E.M. and Cox, J., 'The Goal; Excellence in Manufacturing', North River Press, Inc, Croton-on-Hudson, New York, 1984.

Goyal, S.K., 'Analysis of Joint Replenishment Inventory Systems with Resource Restriction', Operational Research Quarterly, Vol. 26, No. 1, pp. 197-203.

Guinipero, L.C. and O'Neal, C., 'Obstacles to JIT Procurement', Industrial Marketing, Vol. 17 No. 1 p36, January 1986.

Gunder, W., 'Bills of Material Structuring: Modular and Phantom Bills', Production and Inventory Management, pp. 85-89, second quarter, 1978.

Hardy, T.I., 'System Implementation and Evaluation', Journal of Systems Management, Vol. 24, pp. 24-27, December 1973.

Hartland- Swann, J.R., 'MRP or JIT: Which is the Best?', Proc.2nd Int.Conf, Just in Time Manufacturing, pp. 81-92, Nov 1987.

Heard, E., and Plossl, G., 'Lead times revisited', Production and Inventory Management, 3rd quarter, pp. 32-46, 1984.

Hickman, R.I.F., 'Managing Just-In-Time Materials', Proc.2nd Int.Conf, Just in Time Manufacturing, pp. 93-100, Nov 1987.

Jason,R; Warnecke,H.J.; 'Just-In-Time Manufacturing', Proceedings of the 3rd International Conference, IFS Publications, 1988.

Jewitt. R.H., 'MRP V JIT-IS There a Conflict?', Proc.2nd Int.Conf, Just in Time Manufacturing, pp. 125-133, Nov 1987.

Kanet, J.J., 'Towards understanding Lead times in MRP systems,' Production and Inventory Management, 3rd quarter, pp. 32-46, 1984.

Kanet, J.J., 'MRP 96: Time to rethink manufacturing logistic', Production and Inventory Management, Vol. 29, No. 2 pp. 57-61, 1988.

Karni, R, 'A study of lot sizing algorithms', IIE Transactions, pp. 356-366, December 1986.

Kelly, D.A., 'The principles of complex demand', Production and Inventory Management, 2nd quarter, pp. 115-120, 1985.

Kochhar, A.K., 'The Use of Computers and analytical techniques for production planning and control in the British Manufacturing Industry', Computers and Industrial Engineering, 2,3 pp. 163-179, 1978.

LaForge, R.L. and Sturr, V.L., 'MRP Practices in a random sample of manufacturing firms', Production and Inventory Management, pp. 85-89, 2nd quarter, 1978.

Mitra, A.A, Cox., J.F., Blackstone, J.H., and Jesse, R.R., Jr., 'A re-eximination of lot sizing procedures for requirements planning systems: some modified rules', International Journal of Production Research', Vol. 21, No. 4, pp. 471-478, 1983.

Monczka, R.M. and Carter, J.R., 'Electronic Data Interchange: managing implementation in a purchasing environment', The national association of purchasing management, 1987.

Monden, Y., 'Adaptable Kanban Systems Help Toyota maintain their Just-In-Time Production. Industrial Engineering, Vol. 13, pp. 29-46, 1981.

Parnaby, J., 'A systems approach to the implementation of JIT methodologies in Lucas Industries, International Journal of Production Research, Vol. 26, No. 3, pp. 483-92, 1988.

Parnaby, J., Johnson, P., Herbison B., 'Development of the JIT- MRP Factory control system', Production engineer, pp. 17-21, 1987.

Peles.D., 'Intergation of MRP and JIT', Proc.2nd Int.Conf, Just in Time Manufacturing, Nov 1987, pp. 101-109.

Plossl,G.W., 'Manufacturing Control - The Last Frontier for Profits', published by Reston Publishing Company, 1973.

Shaw, R. J. and Regentz, M. O., 'How to Prepare Users for a New System', Management Focus, pp. 33-36, March-April 1980.

Silver, E.A., 'Comments on A near optimal lot sizing model', Prod and Inventory Management, 3rd quarter, pp. 115-116, 1983.

Skinner, W., 'Manufacturing-Missing Link in Corporate Strategy'. Havard Business Review, Vol. 47, No. 3, pp. 136-145, 1969.

St John, R., 'The cost of inflated planning lead times in MRP systems', Journal of Operations Management, Vol. 5, No. 2, pp. 119-128, Feb 1985.

Voss,C.A.; 'Just-In-Time', IFS (Publications) Ltd.

Ward, 'Turning Manufacturing into a Competitive weapon', Proceedings of the 22nd European Conference on Production and Inventory Control, pp. 184-191, Nov 1987.

Wemmerlov, U., 'Comments on A near optimal lot sizing model', Production and Inventory Management, 3rd quarter, pp. 117-121, 1983.

Wemmerlov, U., 'Comments on cost increases due to demand uncertainty in MRP lot sizing: A verification of ordering probability', Decision science, Vol. 16, pp. 410-419, 1985.

Glossary of Acronyms

AUV	- Annual Usage Value (=item's unit cost * average annual demand).
BOM	- Bills Of Materials
CAPM	- Computer Aided Production Management
CFM	- Continuous Flow Manufacturing
EDI	- Electronic Data Interchange
EOQ	- Economic Order Quantity
JIT	- Just-In-Time
MPS	- Master Production Schedule
MRP	- Material Requirement Planning
MRPII	- Manufacturing Resource Planning
OPT	- Optimised Production Technology
ROP	- Reorder Point
SIC	- Scientific Inventory Control
WIP	- Work-In-Progress

Appendix A

IBM Havant

A.1 History of IBM

In 1911 three separate US companies were merged to form the 'Computing-Tabulating-Recording' company - 'CTR' as it was then commonly known. This organisation produced tabulating machines, scales, and time recorders. The newly formed company turned in unprecedented turnovers. Within 13 years the turnover grew by 300 percent and the company was operating across the Atlantic into UK and Europe.

To capture the international image, the company adopted the name "International Business Machine" (IBM) in 1924. In 1949 the IBM World Trade Centre was set-up, to deal with IBM business outside the USA. This was closely followed by the formation of IBM UK Limited in 1951. Today the business is described as being that of providing customer solutions that integrate computer hardware and software to specific customer needs. The IBM corporation is the largest company in its sector with a revenue of over 69 billion dollars and employing approximately 400,000 people worldwide in 1990.

The corporation is split into 3 major divisions:

- a. The US division covering Canada and North America
- b. The EMEA division covering Europe, Middle East, and Africa
- c. The AFE division covering South America and Far East

All the products are developed in a single development location for manufacturing in each of the 3 divisions. Because of the huge costs involved in setting up new production lines, only one manufacturing location has the responsibility of developing a prime process and agreeing a Worldwide Sourcing plan.

A.2 IBM Havant

IBM Havant was established in 1967 and it is now one of 14 manufacturing locations in Europe. IBM Havant employs approximately 1600 full time and over 800 part time people. It occupies over 1 million square feet of office and manufacturing space. Over the years Havant has received several major awards amongst which include:

- a. 1984 - British Quality Award
- b. 1987 - Willis Faber Award
- c. 1988 - Recognised by 'Management Today' magazine as one of the UK's top six factories

Each plant has a specific product mission. Havant's main focus is on disk files, however, it has retained a small interest in its original products. The products in Havant fall into 3 key areas:

- a. Small and intermediate files (main business)
- b. Telecommunications and
- c. Finance systems

All the plants are inter-dependent on each others' products. The product of one plant is a sub-assembly for another, thus forming a complex web of dependencies. Production at Havant predominantly consists of assembly and test operations with some vertical integration of card assembly/test and flexi-circuits.

The organisational structure within Havant is continually evolving towards product aligned business units. There are also strategic groups providing focal points for programs such as:

- a. Continuous Flow Manufacturing (CFM is IBM's term for JIT)
- b. Material logistics
- c. Robotics
- d. Computer-aided manufacturing
- e. Computer Integrated Manufacturing (CIM)
- f. Quality Improvement Programs

Table A.1 - Product Analysis					
<u>Product Group</u>	<u>Complexity</u>	<u>Volumes</u>	<u>Product Life</u>	<u>Costs</u>	<u>Profit Margins</u>
Files	Low features	High (1,000's per shift)	2/3 Years	Low (100's of pounds)	Very Low
Telecommunications	Highly Featurised (But configurations of same basic units)	Low (10's per shift)	3/5 Years	High (1,000's of pounds)	High
Finance Systems	Highly Featurised	Very Low (1's per shift)	5 Years	Very High (10,000's of pound)	Very High

A.3 Materials Planning and Control Systems at Havant

Material and production planning and control is highly computerised at Havant. Discrete examples of such systems have existed since the plant began production some 25 years ago. Since then, the systems have been developed such that Havant now has over 70 computer systems inter-linked together supporting every aspect of the plant's activity.

Of the many systems within Havant, EMLS (Enterprise Material Logistics System) is the most advanced and sophisticated. It is a corporate wide system which was installed in EMEA in 1985. Its success in Europe was followed by installations in the USA, Canada, and Japan in 1989. EMLS is a massive corporate system controlling every aspect of manufacturing right across all the IBM plants. It contains several modules (which are systems in their own right). One such module or system is EPRG (European Parts Requirements Generation). EPRG is IBM's multi-plant MRP system.

A.4 EPRG (IBM's MRP)

EPRG was one of the first modules of the EMLS systems to be installed in 1985. The purpose of installing EPRG was to eliminate the cascading effect of communication between plants. Prior to installing EPRG, each plant would run their own local MRP

and cascade the parts requirements schedule to its supplying plant. The supplier in turn would use this information to run his own MRP and cascade the requirements to the next supplier, who in turn would repeat the process. There were two major drawbacks with this process:

Firstly, the time it took to cascade the requirements to the lowest level supplier was too long. With 14 plants involved, the cumulative lead time was over 6 months. This time did not even include external vendors. Clearly, this was unacceptable in light of today's highly volatile customer environment.

Secondly, because of the inter-dependencies between plants, each plant would have to wait a long time before it received its own inter-plant demands.

The need to cut the planning lead times and the economic climate spurred the development of EPRG. The general objective was to eliminate the overlap of cascade of orders through a chain of several plants. Within this general objective, there are a number of specific objectives as follows:

- a. To enable plants to commit and implement the actions within 20 working days
- i.e. the MRP cycle is 20 days
- b. To use the latest operational data from the plants
- c. To take account of all the excess inventory within EMEA locations before ordering new material from external vendors. That is, an inter-plant customer must buy material from the excess inventory location (at cost) before it is allowed to raise new purchased orders on local vendors. This policy was introduced to minimise the loss through obsolescence. As can be seen from table A.1, the product life cycles in the electronics industry are very short.
- d. To provide overall visibility within EMEA of the current supply and demand situation. That is, each plant can see the manufacturing schedule of its inter-plant

customer. The advantage of this facility is that the supplying plant can challenge the supplied plant if it places any strains on the production facility.

The objective for the supplying plant is to minimise its production costs through efficient use of production facilities - clearly, lumpy or excessive demands will incur additional costs through overtime etc...This is a very critical objective because unplanned costs cannot be recovered - in the current environment market share is maintained through low profit margins. Therefore, unplanned costs will only erode the profit margins further.

A.5 Havant's Challenge

The challenge, particularly to Havant is to be more competitive than other manufacturers in addition to other IBM locations. Havant's focus on files means that much of its competition is with US and Japanese locations. This business sector faces the most fierce competitive pressures:

- a. profit margins are low
- b. rate of product change is high
- c. development costs are very high
- d. quality is critical

In addition to the above pressures, the plant has the manufacturing monopoly for maybe only a year or less. In this time, the development costs must be recovered before the product becomes old technology and loses its competitive edge through 'cloning'. These pressures reflect the need for change. It characterised the current Havant environment and some of the difficulties IBM faces in responding to change.

A.6 Strategic Responses

In order to meet the challenges, IBM has initiated a number of programs over the years.

A.6.1 Quality

As discussed above, quality is critical in the files business as indeed in other businesses. Havant first established a strong quality culture in the late 1970s with a

'zero defect' program in line with its files mission. Its objective was to:

"...to provide products and services to please our customers in terms of delivery, quality, and function at the right price". - from IBM's 'INNOVATION' Magazine, April 1989.

To put it simply, Havant's mission is to become the "lowest cost file producer with zero defects".

It was not until 1980 that IBM Corporation launched a company wide quality drive. Havant was a key driver and a corporate show case because of its head start. In 1980 quality circles were first introduced as the first of many quality improvement techniques. Havant adopted a strategy "in pursuit of excellence..." through a simple program called EXCEL, designed to encourage improvement activity in all of the plant processes. This help lay the foundation for an attitude of continuous improvement.

Encouraged by successes of these early programs; the scope and scale of the improvement projects now extends to encompass every aspect of the business, amongst which include: manufacturing processes, administration, paying suppliers, sales order entry, claiming expenses, complaints procedure etc... To accommodate the volume of improvement projects and encourage cross-functional projects a simple system of monitoring and recognition of performance was introduced.

Early examples of performance improvements include 20-30 percent field performance improvement year on year and vendor conformance achieving a staggering 99.6 percent in 1986. The tangible savings to IBM were 5.2 million pounds from reductions in capital, expense, warrantee, space, inventory, and manpower in 1986. More than half of the projects were of process improvements where the benefits were too difficult to quantify in monetary value.

Today, the quality focus is on 'Market Driven Quality'. It not only focuses on elimination of waste but also on simplification - be it process, procedures, or

products. The quest for quality extends to every single customer, whether internal or external, whether a corporate user or a sole personal computer user. Indeed, the bonus scheme is now dependent on total customer satisfaction. Total quality and team work have laid the foundations for continuous flow manufacturing at IBM.

A.6.2 Continuous Flow Manufacturing (IBM's JIT)

Having achieved high quality and a total quality culture, continuous flow manufacturing was seen as the next logical step in reducing the manufacturing costs. CFM is concerned with doing the right job, without error, and with a focus on continuous improvements. CFM aims to improve the effectiveness and efficiency of the manufacturing process.

The framework for CFM is quality, elimination of waste and simplification. Building on this general framework Havant developed a set of 12 related techniques:

1. WIP reduction
2. Group technology
3. Balanced/mixed production
4. Kanban
5. Tightly coupled logistics
6. Supplier integration
7. Zero defects
8. Management by sight
9. Multi-skilled people
10. Focus team
11. Preventive maintenance
12. Set-up reduction

CFM was seen to affect the TOTAL MANUFACTURING PROCESS, from the time orders are placed with vendors to the time the product has been accepted and performs reliably in a customer's office. To achieve this result, it was seen that material flow, design and development together with order management must be integrated.

Case studies indicate that over an initial period of 18 months, a saving of 27,000 sq ft of manufacturing space, 16,000 sq ft of warehouse space, and inventory reduction

of in excess of 10 million pounds was achieved. This was seen as the tip of the iceberg with further gains to be achieved by continuation, widening, and development of the concept. Havant sees CFM as a "way of life and as such will soon be treated as business as usual".

A.7 Role of Inventory Management within IBM Havant

The structure of Havant plant is broadly divided by business units. One of the business units is the manufacturing operations unit within which lie production, planning, and supply. The planning department is accountable for planning future production, scheduling customer orders, and total plant inventory. Within this general scope, the role of the inventory planner is to:

- a. determine the optimum inventory levels for each product
- b. define procedures for their review adjustment
- c. determine the degree of control required
- d. design the total inventory control system
- e. define the inventory control organisation

It is within the inventory planning function that this project lies. As discussed in earlier chapters, the objective of the project was to help reduce inventory whilst reducing costs and maintaining service levels.

Appendix B

Economic Order Cycle

B.1 EOQ Formula in Terms of Economic Order Cycle

The simple EOQ formula can be written as:

$$Q = \left[\frac{2 \ C \ * \ D}{I \ \$} \right]^{1/2} \dots\dots (B.1)$$

Details of this formula can be found in Corke (1987), Lewis (1981), Thomas (1980) amongst others.

To show:

$$\$D = (2.C/I) * (Y/f)^2 \dots\dots(B.2)$$

Equation (B.2) represents the EOQ in terms of the annual usage value and economic order cycle.

Where

Q	= Economic order quantity
C	= Combined cost of ordering and receiving
\$	= Item unit cost
D	= Annual usage or demand
\$D	= Annual usage value (unit price * annual demand)
I	= Inventory carrying rate (as a decimal)
Y	= Number of working days in standard company year
f	= Order cycle (in days)
Y/f	= Ordering frequency (No of orders per year)
2C/I	= Cost ratio

Step 1 - No of orders in terms of the order quantity and annual demand =
annual demand/order quantity = (D/Q) (B.3)

Step 2 - No of orders in terms of order cycle = days in year/order cycle =
 (Y/f) (B.4)

Step 3 - Combining (B.3) and (B.4)

$$Q = D.(Y/f)....(B.5)$$

Step 4 - Substituting for Q in (B.1) and multiplying through by the unit cost (\$) results in equation (B.2).

B.2 Modified EOQ Formula for Bought-out Parts

For bought out items equation (B.2) can modified to:

$$\$D = (K) * (Y/f)^2(B.6)$$

$$\text{Where } K = 2C/I = \text{Cost ratio}$$

The detailed justification of the modification can be found in Corke and Murdoch (1965). However, briefly, we have to show that the cost ratio $2.C/I$ can be regarded as a constant. First, consider inventory holding rate I . It has been said that the inventory carrying rate is difficult to determine in practice. But whatever its value, it is convenient to regard it as being the same for all parts. However, different items will occupy different space per unit and incur varying rate of handling costs. It is virtually impossible to differentiate between the various items. Further, with several thousand parts the individual cost of holding a part is negligible compared to the total

cost). Therefore, the assumption that I is a constant is a practical one. That leaves us with C , the ordering cost.

The ordering cost C (including receiving cost) for one item is indistinguishable from another. Again with several thousand orders, the cost of an individual order is negligible compared with the total cost, hence it can be considered a constant. In addition, if we adopt the concept of a fixed number of total orders per year, then the total cost of ordering will be unchanged - whatever that cost is.

Since both C and I cannot be realistically identified for individual parts and the individual cost is negligible compared to the overall cost, then the simplifying assumption that the cost ratio is a constant is both convenient and practical.

The conditions that C and I are constants is generally satisfied for bought-out parts. In exceptional cases where either C or I is considered variable, the stock can be sub-divided into groups within which the costs are reasonably constant.

APPENDIX C

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Total Orders and Inventory Series 1						
Policy	Series	Cost Ratio	Classes	Total No. Orders	Inventory Total ('s)	Policy Type
1	1	12.50	6	60657	1762627	GPOQ
2	1	25.00	6	47912	1877266	GPOQ
3	1	50.00	6	38285	2050747	GPOQ
4	1	100.00	6	29468	2367635	GPOQ
5	1	125.00	6	27503	2476929	GPOQ
6	1	150.00	6	25631	2605437	GPOQ
7	1	200.00	6	22955	2836262	GPOQ
8	1	400.00	6	17678	3591337	GPOQ
9	1	800.00	6	13956	4666030	GPOQ

Order Cycles (in days): 5,10,20,40,80,160.

Policy 4 - Prepared by GPOQ

Class	Order Cycle	Lower Class Limit 's	No. of Parts	No. of Orders	Class Inventory ('s)
1	5	115200	194	9312	1374033
2	10	28800	247	5928	307379
3	20	7200	444	5328	278082
4	40	1800	662	3972	213299
5	80	450	704	2112	119030
6	160	0	1877	2816	75812
Totals :			4128	29468	2367635
% c.f. present policy :				154%	47%

Policy 8 - Prepared by GPOQ

Class	Order Cycle	Lower Class Limit 's	No. of Parts	No. of Orders	Class Inventory ('s)
1	5	460800	64	3072	1068122
2	10	115200	130	3120	611822
3	20	28800	247	2964	614758
4	40	7200	444	2664	556164
5	80	1800	662	1986	426598
6	160	0	2581	3872	313873
Totals :			4128	17678	3591337
% c.f. present policy :				92%	72%

Appendix D

Extract From Historical Orders Database

Part No	Value Class	Resch Type	Order No	Order Value	Old Due Date	New Due Date	Due Date Difference
1710381	2	ROUT	2030	5195	5642	5622	20
1884417	2	ROUT	1390	1725	5661	5655	6
1884417	2	ROUT	1400	3451	5666	5660	6
2282675	2	ROUT	1260	2503	5674	5645	29
2282675	2	ROUT	1270	2615	5684	5655	29
2282675	2	ROUT	1280	3508	5659	5640	19
2282675	2	ROUT	1290	1578	5689	5670	19
2282675	2	ROUT	1310	2009	5699	5675	24
2282675	2	ROUT	1320	2471	5704	5689	15
2282675	2	ROUT	1330	2312	5714	5699	15
2282676	2	ROUT	1260	2394	5659	5650	9
2282676	2	ROUT	1270	1756	5669	5655	14
2282676	2	ROUT	1280	3671	5674	5660	14
2282676	2	ROUT	1290	1277	5684	5670	14
2282676	2	ROUT	1300	1452	5689	5675	14
2282676	2	ROUT	1310	2554	5694	5680	14
2282676	2	ROUT	1320	2394	5704	5694	10
2282676	2	ROUT	1330	2554	5714	5704	10
2462458	2	ROUT	270	1664	5617	5611	6
2462458	2	ROUT	280	1783	5632	5620	12
4804600	2	ROUT	742	6095	5634	5589	45
4804600	2	ROUT	743	6095	5654	5605	49
4804600	2	ROUT	745	5079	5654	5614	40
4804600	2	ROUT	746	7619	5678	5634	44
4804600	2	ROUT	747	7619	5698	5645	53
5562063	2	ROUT	290	1183	5632	5611	21
5562063	2	ROUT	300	1065	5639	5620	19
6020261	2	ROUT	228	1902	5678	5614	64
6020261	2	ROUT	232	5434	5634	5601	33
6020261	2	ROUT	235	5434	5654	5601	53
6020261	2	ROUT	236	5434	5678	5622	56
6020261	2	ROUT	237	5434	5698	5622	76
6020261	2	ROUT	238	5434	5718	5634	84
6020261	2	ROUT	239	3895	5738	5645	93
6028789	2	ROUT	1870	2346	5669	5650	19

Part No	Value Class	Resch Type	Order No	Order Value	Old Due Date	New Due Date	Due Date Difference
1884222	3	RIN	116	843	5597	5612	-15
1884222	3	RIN	118	552	5612	5632	-20
1884346	3	RIN	127	300	5637	5657	-20
1884346	3	RIN	128	801	5612	5622	-10
1884346	3	RIN	130	601	5652	5672	-20
1884347	3	RIN	116	218	5652	5677	-25
1884347	3	RIN	117	872	5622	5642	-20
1884347	3	RIN	119	654	5662	5686	-24
1884482	3	RIN	598	4530	5640	5672	-32
1953762	3	RIN	520	836	5610	5620	-10
1953762	3	RIN	530	1541	5630	5640	-10
2274833	3	RIN	190	1054	5607	5620	-13
2392485	3	RIN	1040	800	5618	5640	-22
2392485	3	RIN	1050	728	5643	5665	-22
2452458	3	RIN	170	974	5607	5620	-13
2452458	3	RIN	220	1451	5610	5620	-10
2666958	3	RIN	1210	651	5604	5610	-6
2666958	3	RIN	1220	651	5614	5620	-6
5145451	3	RIN	144	1624	5575	5619	-44
5145451	3	RIN	145	1624	5619	5637	-18
5146722	3	RIN	118	999	5598	5605	-7
5146722	3	RIN	119	999	5603	5613	-10
5146723	3	RIN	113	496	5608	5613	-5
5146723	3	RIN	114	330	5613	5628	-15
5148632	3	RIN	1600	393	5647	5660	-13
5148632	3	RIN	1660	1311	5651	5665	-14
5148632	3	RIN	1670	1049	5676	5689	-13
5252827	3	RIN	470	864	5652	5665	-13
5252827	3	RIN	480	319	5647	5661	-14
5252827	3	RIN	490	1080	5671	5686	-15
5351156	3	RIN	760	670	5613	5625	-12
5351156	3	RIN	770	670	5618	5650	-32
5351156	3	RIN	780	670	5628	5660	-32
5351156	3	RIN	790	670	5649	5670	-21
5351156	3	RIN	800	335	5654	5689	-35
6264705	3	RIN	620	372	5605	5615	-10
6264705	3	RIN	630	447	5611	5625	-14
6398627	3	RIN	970	207	5596	5605	-9
6398627	3	RIN	980	930	5600	5605	-5
6423155	3	RIN	171	1232	5606	5626	-20
6423322	3	RIN	380	748	5604	5694	-90