ASPECTS OF THE DESIGN AND OPERATION OF PRODUCTION CONTROL SYSTEMS IN MANUFACTURING INDUSTRY

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SYNOPSIS

Computerised production control developments have concentrated on Manufacturing Resources Planning (MRP II) systems. The literature suggests however, that despite the massive investment in hardware, software and management education, successful implementation of such systems in manufacturing industries has proved difficult.

This thesis reviews the development of production planning and control systems, in particular, investigates the causes of failures in implementing MRP/MRP II systems in industrial environments and argues that the centralised and top-down planning structure, as well as the routine operational methodology of such systems, is inherently prone to failure.

The thesis reviews the control benefits of cellular manufacturing systems but concludes that in more dynamic manufacturing environments, techniques such as Kanban are inappropriate. The basic shortcomings of MRP II systems are highlighted and a new enhanced operational methodology based on distributed planning and control principles is introduced.

Distributed Manufacturing Resources Planning (DMRP), was developed as a capacity sensitive production planning and control solution for cellular manufacturing environments. The system utilises cell based, independently operated MRP II systems, integrated into a plant-wide control system through a Local Area Network.

The potential benefits of adopting the system in industrial environments is discussed and the results of computer simulation experiments to compare the performance of the DMRP system against the conventional MRP II systems presented. DMRP methodology is shown to offer significant potential advantages which include ease of implementation, cost effectiveness, capacity sensitivity, shorter manufacturing lead times, lower working in progress levels and improved customer service.

KEY WORDS: Distributed Manufacturing Resources Planning, Manufacturing Resources Planning, Computerised Production Control, Cellular Manufacturing Systems

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CHAPTER 1 INTRODUCTION

This thesis explores the main production planning and control problems facing the western industrialised countries. It explores the background to the development of manufacturing control systems and introduces a new production planning and control philosophy which significantly improves the effectiveness of computerised manufacturing control systems.

The research was largely financed by BT Fulcrum Plc., a manufacturing subsidiary of British Telecom PLc. BT Fulcrum, manufacture electronics equipment ranging from telecommunications to bespoke computerised systems. During the course of the research, BT Fulcrum management further supported the research by allowing free access to their manufacturing operations and their MRP II system. The research was seen as a means of contributing to the development of their long term manufacturing strategy options.

1.1 BACKGROUND TO THE ISSUES CONCERNING THE MANUFACTURING INDUSTRIES

Ever since the start of the industrial revolution, which began in England and spread across the rest of the world, the manufacturing industries have played a primary role in greatly enhancing economic prosperity, and thus the living standards, of the industrialised countries. However, with the prominent rise of Japan and other Far Eastern countries, over the last 40 years, as major industrial nations and the continuing dominance of their manufacturing industries, all the western industrial sectors faced increased competition. In the 1970's as the market share of textile, shipbuilding and electrical appliance manufacturers started to diminish, the tendency in the West was to blame Far Eastern countries for emulating and mass producing their products by using cheap labour. The fact that Western consumers found Japanese products to be of superior quality was largely ignored.

During this decade the Japanese were adopting radically different approaches to the issues of quality and manufacturing techniques. The term 'zero defects' was established as the ultimate goal for their manufacturing industries. Furthermore, Western consumers, accustomed to long product life cycles, noted design improvements with ever increasing frequency, which further deteriorated the competitive position of the indigenous manufacturing industries.

Following the Organisation of Petroleum Exporting Countries (OPEC) cartel's successful attempt to quadruple the price of oil in 1974 and the ensuing recession, a concerted effort was made to radically improve the competitive position of the manufacturing industries, starting with the Material Requirements Planning (MRP) crusade in the U.S.A., which was followed by Europe. Belatedly, inventory turnover, which is an important indicator of a manufacturing company's performance, was recognised as an area where the competitive gap could be reduced. MRP systems were considered an important management tool in achieving enhanced inventory turnaround. The small number of companies which successfully managed to implement an MRP system, reported reductions in their overall inventory levels and work in progress

(WIP), and a doubling of inventory turnarounds. The average number of turnarounds was still in single figures,but some Japanese industries were already achieving between ten and twenty per year.

The Japanese Just In Time (JIT) philosophy clearly contributed to their success in reducing overall inventories. The MRP systems however, were mainly implemented in factories without major reorganisation. In most cases the acceptance of inventories as assets instead of liabilities led to MRP systems incorporating the old inventory management techniques such as Economic Order Quantities (EOQ) and Re-Order Point (ROP).

A positive feature of implementing an MRP system was the establishment of computerised databases and the imposition of formal management procedures. These data bases were subsequently used to integrate the management control systems. The evolution of MRP to Manufacturing Resources Planning (MRP II) was considered as a further breakthrough in introducing state-of-the-art techniques into manufacturing companies.

The relative advantages of such systems however, proved no match to the Japanese approach to manufacturing management and the introduction of new consumer products with ever decreasing product life cycles resulted in the competitive gap being widened. Essentially computers were viewed as panacea for all the ills of manufacturing industries. Not only they were difficult to implement, but the actual methodologies and centralised computing structures compounded the problems.

Companies again looked to computers to provide solutions to these new man made problems. In the last decade a whole host of new computerised solutions have been put forward as the best way forward to catch up with the Japanese. These include Flexible Manufacturing Systems (FMS), Advanced Manufacturing Technology (AMT), and Computer Integrated Manufacturing (CIM).

Little effort has gone into identifying the fundamental philosophical inconsistencies of Western management techniques. Any computerised solution seems to find a ready market. The problem, it is argued, lies in the incoherent development of such solutions. There is a need to go back to the first principles and ask what has gone wrong and what should be done to get on course and to compete in the world markets.

The thesis has reviewed the manufacturing control systems which are dominant in the manufacturing industries, and attempted to identify the core issues which must be addressed. The analysis which will follow in chapters 2 to 11, will guide the reader through developments in the field of production and inventory planning and control, focusing on the major issues which were ignored . The fundamental inconsistencies of the various techniques will be explored and suggestions will be made about areas where improvements can be made.

The discussion will then focus on the MRP/MRP II systems, which are the dominant type of computerised production and inventory planning and control systems in the West. The fundamental flaws in the methodologies will be reviewed and a new simplified and coherent methodology will be introduced. The new technique which is based on a distributed form of manufacturing management, utilises commercially available micro computer based MRP II systems, hosted on a Local Area Network (LAN). Distributed Manufacturing Resources Planning (DMRP) is based on the distribution of control across autonomous cells. Links between the local cell based systems and a new operating methodology, permit capacity sensitive planning and control of manufacture.

In order to investigate the operational policies and the potential performance of the DMRP, a computer simulation model of a factory was developed. The results of these experiments will be presented, as well as suggestions for further research.

CHAPTER 2 BACKGROUND DISCUSSION ON THE CONTROL OF THE MANUFACTURING ENVIRONMENT

The discussions in this chapter will explore factors influencing the the manufacturing control problem, as well as, the basic mechanisms of production planning and control systems. The elements of manufacturing management and the role of manufacturing control systems in achieving corporate objectives will also be discussed.

2.1 FACTORS INFLUENCING THE MANUFACTURING CONTROL PROBLEM

Goldratt (1984), defined the goal of a manufacturing plant as first and foremost, to make money. This definition leads to the establishment of the action plans at the plant level. Doumeingts et al (1981), in a discussion on the structure of production planning and control systems wrote:

> "The aim of a plant is to change "products" given by (material, machine, workers) into "products" asked by customers. This transformation is realised according to objectives given by the chief management, with regards to performance criteria. These criteria are generally concerned with:
>
> - due dates defined by commercial centres,
> - quality required by customers or production managers,
> - production costs, inventory levels determined by general managers.
>
> Quite often, these criteria lead to conflicts between the objectives. So the production decision makers have to choose

> and find compromise solutions, according to the constraints...Improving performances leads to a well organised resources scheme. Such an organisation is a decision problem about the synchronisation of resources between the various departments of the firm... Decisions may be classified in three groups: strategic, administrative and operational.".

Clearly, the pursuit of the ultimate goal, relies on the basic commercial doctrine, to maximise the return on the capital employed. In manufacturing environments, the purchase and maintenance of plant and equipment, require capital and steady sources of cashflow from the saleable throughput of the plant. The cashflow is directly dependent on the stream of customer orders. The customers, however, only continue to place these orders, if they perceive overall satisfaction with the service being provided. The manufacturing planning and control, directly links to this vital chain of dependencies. The customer measures satisfaction in the quality of the product in relation to the price paid as well as the other related services including the timely delivery of the product. The link is further influenced by the relative performance of the competitors. Here, the lead time of an order plays a very important role. If the competitors can deliver to the same quality of service with shorter lead times, the chances of repeat orders are considerably reduced.

With the advent of global competition, organisations have to compete with the customer service performance of their best competitors. Quality, price and short and consistent delivery lead times are relatively new standards which have been imposed on the western industrial culture by eastern competitors, Dear (1989). The Japanese approach to maintenance of customer loyalty through adoption of quality and consistent manufacturing performance improvements, will be discussed further in section 4.2. It is ironical however, that the industry-wide solutions which they adopted should have been the products of isolated efforts of western practitioners dating back to the 1920s.

The realisation of the goal of the manufacturing organisations, necessitates the use of an effective approach to the planning and execution of management tasks. The control of the activities required to perform the above objective, is achieved through the use of some form of production and inventory planning and control system. The most dominant of such systems and their respective philosophies will be discussed in detail in chapters 4, 5 and 6. However, the Japanese and western industrialised countries whilst both aiming for the same broad global objectives (to make money), tend to differ in their approach to production planning & control mechanisms they employ. The difference in the control of their productive capacity and a suggested improvement to the existing production control norms will form the bases of the following discussions.

2.2 BASIC MECHANISMS IN PRODUCTION & INVENTORY CONTROL SYSTEMS

The objective of any control system is to ensure that for any process or activity under control, the desired behaviour is attained. Production and inventory control systems, attempt to control the manufacturing plant utilising the same control elements as those used in control theory, and as such can be described as 'controlled systems', Monhemius (1981).

Aken (1978), defined the two basic controlled systems as follows:

> "A *servomechanism* is a controlled system, designed so that its output will follow a given "reference signal" (a certain time function or time series) as closely as as possible... Maintaining output equilibrium in a changing environment can be described as a servomechanism activity, the demand for output forming the reference signal. A *demand servo* is an industrial conversion system designed so that its material output follows the external potential demand for this output.".

The demand servo, in a manufacturing environment could contain manufacturing units, stockpoints, distribution and a control system. In a manufacturing environment, there are specific management functions which could be controlled utilising appropriate features of a control system.

Wagner (1974), defined six management functions in a large scale organisation, which could be contained within an overall control system:

* *SALES FORECASTING*
* *PRODUCTION PLANNING*
* *PRODUCTION SCHEDULING*
* *MATERIAL ORDERING*
* *DISTRIBUTION PLANNING*
* *CUSTOMER ORDER PROCESSING*

The use of feed forward/ feedback, in isolation or together, defines the characteristics of a control system. The master production scheduling function within MRP systems, which facilitates the calculation of quantities of manufactured and purchased components required and the time when they are required (acting before before the demand has actually happened), could be described as a feed forward mechanism within the production planning and control system.

The calculation of demand for the dependent components in the manufacture of a product, in MRP systems, classifies it as a deterministic system. Whereas, the determination of levels of stocks for the manufacture of end items based on the statistical analysis of the past demand, is classified as a stochastic system. Mathematical modelling techniques rely on the feedback through a reorder point to trigger a new replenishment cycle. The order quantities however, are generally calculated based on the past usage and past delivery lead times. The deterministic approach to the calculation of required quantities based on the bill of material (BOM) data for a given end product, nevertheless, introduces additional production planning and control complexities which need to be highlighted.

The calculation of dependent quantities based on the BOM, relies on the past lead time data to time phase the requirements. This lead time data by it's nature is retrospective information. However, the dynamic behaviour of the production plant (and by implication the lead time performance data) is influenced by many factors (ie, product mix, the batch quantities and the transient bottlenecks in the productive resources etc.) which are subject to variations and therefore, stochastic in nature.

Kanban cards in the JIT system rely on the feed back signal from a cell to start producing more of another small batch of the required component. Here, the flow of production is determined by the actual need for more components, therefore, if a machine breaks down or an operator is slowed down temporarily for any other reason, this stochastic plant phenomenon is reflected in the time taken before a feedback signal is received to produce a further batch of any required component. The benefits in reducing the overall work in progress and the visibility of the causes of slow down in the rate of production, are a favourable feature of such an approach. Monhemius (1981), wrote:

> "I think, MRP is a very useful and very practical concept. For that very reason it would be a pity when the pendulum would move back too far to only deterministic thinking and only feed forward control mechanisms. In Japanese papers by Toyota people we read that because of the disadvantages of the deterministic 'classical push-methods' they added their 'Kanban-system', essentially a pull method to deal with stochastic phenomena. The former can be considered feed forward, the latter feedback.".

The use of Kanban however, is limited to repetitive manufacturing, whereas, MRP systems could be used in any manufacturing environment. It is suggested that a satisfactory compromise approach should be developed which would combine the best features of the feed forward and feedback mechanisms, within a production and inventory planning and control system, to enhance the operational control of the productive resources of manufacturing organisations.

The development of such a mechanism, is the basis of this thesis. However, it should be noted that the above suggestion would only be a micro element of a complex macro control system which forms the total manufacturing organisation and its related support functions. Other elements of manufacturing management which influence the successful control of a manufacturing organisation will form the basis of the following discussions.

2.2.1 ELEMENTS OF MANUFACTURING MANAGEMENT

The manufacturing activities, as was stated earlier, play an important role in the achievement of an organisation's ultimate goal. Merchant (1982), in a study of the major factors influencing the manufacturing productivity, found that 60% of the improvements are a result of the improved production technologies, which include the way the organisation plans and executes the production processes.

The manufacture of products to the satisfaction of customers, would require a manufacturing plant to work towards that aim whilst maintaining and steadily increasing overall profitability. The control of raw material, work in progress and finished goods levels (unproductive capital tied up in the system), clearly affects the profitability of the enterprise. Specifically in a batch manufacturing environment, the achievement of high inventory turnaround has not been a consistent feature. Studies by Hollier et al (1966) and

Dudley (1970) have highlighted some of the factors which lead to this unsatisfactory state. Figure (2.1), demonstrates Dudley's comparative productivity analysis of U.K. industries.

Hollier et al, found a linear relationship between the number of operations needed to produce the average batch and the mean throughput time.

They concluded that throughput time was influenced mainly by the ratio of work-load to available productive capacity. As capacity utilisation approaches 100%, long queues occur, resulting in high work in progress.

They further concluded that since 90% of the throughput time was consumed in non productive work in progress stages of manufacture, the batch size and process time had little effect on the overall throughput times. These considerations, led them to the more general conclusion that an undue emphasis on high machine utilisation only results in excessive work in progress and long throughput times. (a conclusion which forms the basis of the recent OPT philosophy discussed in chapter 4.3.2). Complex and long process routes, are a further source of uncertainty which add to the control problem. Gallagher et al (1986), wrote:

> "In traditional batch production industry, we firstly separate the manufacture of parts by operations needed to make them and then tediously carry them from one department to the next. In a survey of one plant for example, it was discovered that parts made a 4.5 mile circuit through their various processing steps. Long and uncertain throughput times are the source of the delivery problem which so often exists for the customer of small batch manufacturer. This is not a minor problem, as individual parts are eventually assembled and the late arrival of one part can hold up the completion of the total assembly. This results in stocks being kept to ensure against such non-delivery."

The above is a testimony to a confused approach to the design of manufacturing systems. The literature suggests that the absence of a well defined manufacturing strategy which attempts to satisfy the corporate objectives of an organisation in respect of every type of service including customer service, is a common feature of many organisations. At a higher management level, the elements of control require a well defined set of objectives which guide an organisation in its routine management. The successful companies both in Japan and western industrialised countries, rely on a clearly defined set of objectives which logically interlink to the lower level productive elements of the organisation. The process of defining the production planning and control needs of an organisation, would benefit from the existence of manufacturing control mechanisms which would simplify the implementation of closer co-ordination between manufacturing strategy and corporate strategy. New production planning and control systems it will be argued, should facilitate the implementation of such a philosophy at the design level. Kruse (1987), wrote:

> "MRP, MRP II, GT, JIT, FMS, CAPM, etc. are only meaningless terms to divert management attention from the real needs of the business, unless they are considered as part of an overall business strategy."

It is suggested that the design of manufacturing control systems should be carried out in conjunction with the broad corporate objectives of an organisation. Therefore, awareness of issues relating to corporate and manufacturing strategy development, would enhance such a design process. The following discussions will briefly highlight some the important issues which should be considered.

2.2.2 IMPORTANCE OF MANUFACTURING STRATEGY

The importance of manufacturing strategy as an integral part of corporate objectives, has been well documented, Malpas (1987), Wheelright (1978), Krupp (1982), Skinner (1969), Skinner (1974), Skinner (1978), Rimmer (1987). However, corporate strategy and the production planning and control decision making process, are often divorced. Wheelright, concluded that:

> "In spite of the fact that manufacturing frequently accounts for the majority of a firm's human and financial assets, top management often overlooks the role that operations can play in accomplishing corporate objectives.".

Rimmer (1987), in a discussion on the need for manufacturing strategy wrote:

> "In many companies, manufacturing may be likened to the engine room of an old-fashioned steam ship; everyone involved is busy working away keeping the boiler going and the pistons moving, but they rarely have any idea as to where they are headed! Meanwhile, on the bridge, the navigating officers are unconcerned with the details of what goes on in the bowels of the ship provided it continues to function. 'Captains of industry' unfortunately have for too long only paid attention to the manufacturing function when things go wrong. It is becoming increasingly important to recognise that a corporate business strategy is incomplete unless it includes a coherent manufacturing strategy.".

The literature suggests that, to date, the lack of appreciation of industrial engineering functions by top executives who draw up the corporate plans, has largely remained unchanged. Therefore, the routine manufacturing policies, which have a direct effect on the boundaries of commercial strategic planning, tend to be based on misconceptions or misunderstandings. Rimmer, wrote:

> "Manufacturing can only be an effective tool when its policies are consistent with the recognised priorities of the company as a whole. Manufacturing 'strategy' should not be concerned merely with 'fire-fighting' but provide a means of integrating operational capability with current and future business plans.".

Skinner (1969), highlighted several examples of companies that had made costly and avoidable mistakes through lack of effective integration of policy making between the senior executives and the production planners. The following company produced five kinds of electronic gear for five different groups of customers:

> "The gears ranged from satellite control to industrial controls and electronic components. In each market a different task was

> required of the production function . For instance, in the first market, extremely high reliability was demanded; in the second market, rapid introduction of a stream of new products was demanded; in the third market, low costs were of critical importance for competitive survival . In spite of these highly diverse and contrasting tasks, production management elected to centralised manufacturing facilities in one plant in order to achieve 'economies of scale.' The result was a failure to achieve high reliability, economies of scale, or an ability to introduce new products quickly. What happened, in short, was that the demands placed on manufacturing by a competitive strategy were ignored by the production group in order to achieve economies of scale. This production group was obsessed with developing 'a total system, fully computerised'. The manufacturing program satisfied no single division, and the serious marketing problems which resulted choked company progress.".

In another organisation the strategic sense, was to maximise output to satisfy increased demand from key customers. However, the production control systems employed in the plant were set up, as they had been for years, to minimise costs. As a result, long runs were emphasised. While costs were low, many customers had to wait, and many key buyers were lost. Consequently, when the new plant came on stream, it was forced to operate at low volumes. Given the need for a more effective integration, Skinner's, examinations of this problem have highlighted a pattern of failure, which combines the following two factors:

(1) A sense of personal inadequacy, on the part of top executives, in managing production.

(2) A lack of awareness among top executives that production systems inevitably involve tradeoffs and compromises and so must be designed to perform a limited task well, with that task defined by corporate strategic objectives.

Skinner (1969), wrote:

> "The production area of a company is either a weapon in the fight with the competitors or a burden. It is rarely neutral. The connection between production and the success of the company is mostly restricted to the aim of achieving low operational costs and high efficiency. In real life, the connection is far more critical and delicate. Not many top managers have recognised that decisions which appear to be run-of the mill production decisions regularly restrict the strategic choice available to the company by forcing the enterprise into a no longer competitive situation whose fundamental improvement may take years."

Company-wide integrated planning and control, has not been successfully implemented in sufficient numbers. Practitioners have tried implementing integrated computerised systems, by connecting the existing Management Information Systems (MIS) such as the accounts and the conventional Manufacturing Resources Planning (MRP II), with mixed results, Kruse (1987), Oliver (1987), Goldratt et al (1984).

It is suggested that even in organisations where first-rate managers are employed, the task of translating corporate strategy into the manufacturing planning and control decision making procedures, can be extremely difficult, Skinner (1974), Rimmer (1987). The problems it is argued, result from the departmental decisions which whilst appearing appropriate to a local task, could act counter to the broader global aims of an organisation.

Traditionally, the manufacturing plant has been viewed by non production engineers, as a complex logistical problem, which requires specialists with highly technical qualifications to operate successfully. Therefore, any new machinery or computerised planning and control system which is sold to them as simplifying the function, is purchased with little awareness of its true worth to the process of manufacturing in the plant.

Conversely, the senior executive positions , from the line managers point of view, appears to be driven by accountants and marketing people, who speak a different language to them and seem to have no grasp of the difficulties of the processes of manufacture, inventory and quality control. Indeed it is often said that the reason for the comparative success of West German industries, over their U.K. equivalents, is the fact that senior executives are promoted from the line management positions, thus appreciating the complexities of the day to day production planning and control. Skinner (1969), wrote that his research indicated that:

> "Instead of focusing first on strategy, then moving to define manufacturing task, and next turning to systems design in manufacturing policy, managements tend to employ a concept of production which is much less effective. Most top executives and production managers look at their production systems with the notion of 'total productivity' or the equivalent, 'efficiency.' They seek a kind of blending of low costs, high quality, and acceptable customer service. The view prevails that a plant with reasonably modern equipment, up-to-date methods and procedures, a cooperative work force, a computerised information system, and an enlightened management will be a good plant and will perform efficiently.".

He argued that the questions 'what is a good plant ?', 'What is efficient performance ?' and 'what should the computer be programmed to do?', need to be specifically addressed in relation to corporate strategy. Furthermore, the yardsticks of success should be more precise than 'efficiency' or 'productivity'.

Research into the process of manufacturing policy determination has identified the following elements as important considerations for successful incorporation of manufacturing planning and control into a company's corporate strategy.

(1) **Competitive situation**

Determination of the number, kind, resources, trends and the strategic and tactical activities of the competitors.

(2) **Assessment of the company's assets**

These include the financial, human and technical resources.

(3) **In-house competitive strategy**

Critical evaluation of available options and incorporation of the optimal strategy into a detailed game plan.

(4) **Manufacturing planning and control evaluation**

Detailed analysis of the manufacturing capabilities, including assessment of anticipated service and quality levels. Frequently, opportunities arise to incorporate new enabling technologies both into the manufacturing process and production planning and control systems, in order to achieve the in-house competitive strategy.

(5) **Periodic analysis and review**

Systematic reviews of the game plan in relation to the prevailing market conditions, together with monitoring of plant activity to ensure synergy between manufacturing policies and corporate strategy.

It is therefore, suggested that since the above key points are inherently logical, and since the literature suggests that they have not been a consistent feature of the manufacturing organisations, the simplification of the manufacturing planning and control mechanisms is a vital area which should receive special attention. The senior executives, as the above discussions argued, view the management of the manufacturing plant as a complex task. The validity of their view based on the existing plant management practices, is hard to disputed, however, the status quo, should be challenged and attempts should be made to develop an alternative approach to manufacturing planning and control which would improve on this unsatisfactory feature of manufacturing organisations.

2.3 CONCLUDING REMARKS

The discussions in this chapter argued that the achievement of the corporate goals are best realised when an effective link between corporate and manufacturing strategies is established. However, this task is often made difficult due to the incoherent nature of the plant management practices which have been employed.

It will be further argued that an investigation of the issues and the mechanisms of production planning and control systems would seem an appropriate first step in the right direction. Whilst the above appears self evident, a review of the developments in the field of production planning and control systems suggests that, whilst there have been a number of effective techniques developed to simplify the organisation and management of the manufacturing plants, they have not been the dominant techniques and philosophies, largely adopted in the West. Chapter 3 will highlight these developments and will discuss some of the most damaging developments in this field.

CHAPTER 3 AN OVERVIEW OF THE DEVELOPMENTS IN PRODUCTION PLANNING AND CONTROL

The main theme of this chapter will be to explore the developments in the production planning and control systems, to briefly highlight the underlying trends in such developments and to help establish current state of the arts thinking in this area in the subsequent discussions.

3.1 EARLY DEVELOPMENTS IN PRODUCTION & INVENTORY CONTROL

The following examples represent a selected and non exhaustive sample of important events in the history of production and inventory control:

1765 De Gribeauval: A French general who according to Reinfeld (1987) may have been:

> "...the first to propose the idea of interchangeability between parts of weapons as functioning in much the same way as fresh troops replace those fallen on the field.".

1775 Adam Smith: First recognition of economic gains from division of labour.

1789 Honore Blanc: With the support of the French military (De Gribeauval) set up an armoury at Vincennes specifically for the purpose of producing muskets with uniform locks. The French revolution ended the project and government support. With the influx of military personnel to America, the uniformity concept gained ground and Colonel Wadsworth, adopted the motto;

"Uniformity, simplicity, and solidarity.".

1830 ***Charles Babbage:***: Developed Adam Smith's ideas and raised provocative questions about production organisation and economics.

1847 Samuel Colt: Received a government contract for pistols that specified that the parts be sufficiently uniform as to require only a slight amount of filing or refitting.

1853 ***J.E. Brown:*** Invented vernier calliper to 0.001 in. accuracy.

1890 ***Mass production transport products:*** Through a host of enabling technologies such as: precision cylindrical and rotary grinding, ball bearings, pneumatic tyres, flexible cable control, free wheeling, the differential axle and better roads.

1905 ***Fredrick W. Taylor:*** Father of scientific management. Actual beginnings of production organisation, labour control, layout and production control as areas of study and investigation. He believed that no system can do away with the need for real men. Both system and good men were needed.

1911 ***Frank and Lillian Gilbreth:*** Development of motion study.

1915 ***F.W.Harris:*** First application of mathematical models to inventory control and the dawning of a new area of research which to date continues in the operational research field.

1916 Henry Ford: Following the gradual reductions in the price of the MODEL - T FORD between 1908 and 1916 and the introduction of the $5.00 eight hour day in 1914, he eventually lowered the price of his basic model to $ 360. A breakthrough in the total philosophy of manufacture was established. The concept of interchangeability was established as the norm. Reinfeld (1987), described the significance of Ford's mass production techniques in the following manner:

> "Inherent in the idea of mass production is the old concept, dating back to the classical Greeks, of the benefits from the division of labour. But the the Greek philosopher's appreciation of these benefits resulted from a recognition that the crafts had to be learned, and craftsmanship provided benefits in both quality and economy of output. In no case did ***Plato*** or other classicists advocate reducing the skill of the craft to such simplicity and standardisation that the need for craftsmen was totally eliminated, so that they could be replaced by unskilled labour. This is exactly what Ford accomplished. Ford used his highly creative technicians to replace the journeyman with the untrained worker. He broke the job down into simple steps that anyone could do.".

1925 Development of Group Technology: Flander (1925), presented a paper to the American Society of Mechanical Engineers, describing how for the manufacture of machine tools, difficulties in manufacture and production control were avoided by using an approach which was later termed Group Technology. Flanders's approach was according to Gallagher et al (1986), based on:

> " .. standardisation of product, departmentalisation by product rather than process, minimised transportation, visual control of work itself instead of remote control by records.".

1926 Development of Period Batch Control: According to Burbidge (1971), Giggling first developed the feedforward production and inventory planning system . Burbidge, gave the following example:

In week 45 we will build 10 cars type AFK

- Therefore in week 44 we will produce 10 x 5 wheels type AFKW

- Therefore in week 43 we will receive 10 x 5 tyres

....

Monhemius (1981), described the above development as:

> "An early version of MRP with special form of lot sizing.",

pointing out that by the 1930s , Gantt charts and Codell planning boards were increasingly being used for production planning and control.

Between 1900 and 1930s, thinking in models began to develop, Erlang invented queuing theory, and Harris Camp and others describe the first developments in the field of inventory control using the optimal lot size formula.

During the next thirty years, the literature points to an unprecedented growth in the scientific management techniques. In this period there was a growth in the development and use of stochastic models and feedback control mechanisms. Application of applied statistics to industrial environments, in particular once it was realised that the number of observations necessary to reach a given level of accuracy could be calculated, is an example of developments in this period.

Operational research and cybernetics, in conjunction with the developments in mathematical modelling were increasingly applied to various industrial applications. The use of Shewhart quality control charts as a form of feedback loop to indicate influences other than random in the process under control was introduced, and the Industrial Engineering hand-book, Maynard (1956), allocated a chapter to operational research covering subjects like statistics, automatic feedback control and tools & methods of operational research.

The references made to the feedforward/feedback systems in this thesis, are quoted in the context of control theory. In any given situation a distinction would have to be made between:

(1) the situation to be controlled;
(2) the control system or systems;
(3) the models needed to predict the behaviour of the situation under control.

Monhemius (1981), recognised the potential for misinterpretation and argued:

> "Sometimes a distinction is made between feedback and feedforward. In the case of feedback the intervention is applied after the observation of non-preferred system behaviour; in the case of feedforward, the system behaviour is predicted and an intervention is applied, if possible, before the predicted non-preferred behaviour occurs. ..... The main difference between them is the evaluation of behaviour; feedback evaluates actual behaviour, feedforward, predicted behaviour." .

These techniques were used in inventory control theory making use of feedback to fight unexpected deviations; since in stock control deviations are cumulative. Forecasting techniques were increasingly used utilising univariate methods like single variable exponential smoothing with some reference to the potential use of feed forward/feedback control theory applied to inventory control. Magellan (1958), in a discussion on the use of such techniques wrote:

> "The techniques and concepts of servo theory have been found particularly useful in studying the design of efficient fixed-period systems. .. some concepts of servo theory which are important in inventory control are feedback, lags on reaction times, the type of (integral, differential) and the notion of stability.".

Magellan, also described how it was possible to build up seasonal stocks to anticipate seasonal demand.

The above described some of the major early developments related to the field of production planning and control. Literature suggests, that since 1915 when F.W. Harris started the trend towards the application of mathematical modelling techniques to inventory control problems, the use of mathematical modelling techniques, across a wide range of production and inventory planning areas, has received a considerable amount of attention. To date, the Economic Order Quantity (EOQ), formula remains the basis for many new operational research techniques, Bestwick et al (1982).

3.2 THE GROWTH OF MATHEMATICAL INVENTORY CONTROL MODELS

The following discussions will highlight the phenomenal growth in the number of both the static and dynamic mathematical modelling techniques, briefly discussing their practical limitations and some of the convenient but not necessarily appropriate assumptions which accompany such techniques. It will be argued that in practical industrial environments where competitive pressures require the most efficient use of capital, these techniques have limited applicability. The optimisation of specific elements of a global enterprise are outdated and inappropriate mechanisms to achieve competitive advantage, Goldratt et al (1984).

Aggarwal (1974), in a comprehensive review of inventory theory and its applications classified the research efforts based on similarity of approaches into the following six categories:

- *I. Models for the determining of optimum inventory policies.*
- *II. Lot-sizing optimisation.*
- *III. Optimisation of various specific management objectives.*
- *IV. Models for optimising highly specialised inventory situations.*
- *V. Applications of advanced mathematical theories.*
- *VI. Models bridging the gap between theory and practice.*

The detailed mathematical formulas of the models described in this chapter have been presented in the literature, Aggarwal (1974), Zangwill (1966a), Zangwill (1966b), Boylan (1967), Porteus (1971), Beesack (1967), Bessler et al (1966), Clark et al (1960), Hochstaedter (1970), Curry et al (1970), Morton (1971), Evans (1968), Hausmann et al (1972), Hayes (1969), Beckman (1964).

For every category listed above Aggarwal (1974) found as many as eight further general types of models. It is suggested that, the belief in the doctrine of maximum utilisation of resources (regardless of the effects it might have on the global model of an enterprise) is the basis of the EOQ formula and many of it's derivatives.

Central to the formulation of these mathematical models is the assumption that complex factors influencing the performance of an enterprise (such as late delivery of customer orders), can be in some way be expressed mathematically. For example Heron (1967), developed a graphical and algebraic method for determination of minimum cost quantity to be ordered in a reorder point model. He had to find estimates for the order cost and stock holding costs which it can be argued is not too difficult a task. However, he also estimated the the standard deviation between the actual and expected demand during lead time, the stock-out penalty cost per stock-out and the probability of stock-out at each replenishment occasion. Whilst it is true that such information may be statistically collected and given a degree of confidence, it is argued that in an industrial environment such factors would be difficult to determine accurately since the dynamic nature of the markets ensure variations across a range of factors which are critical to the calculation of these optimum quantities.

It is further suggested, that the application of such models will lead to the determination of 'optimum' quantities based on previously estimated data which, at the next replenishment cycle, might not be correct. St. John (1984), wrote:

> "Every exotic lot-sizing method basically attempts to balance inventory carrying costs with order or setup costs in one way or another. Yet the usual means for describing these major cost factors are frequently incorrect. A good case can be made for the fact that the only relevant costs to lot-size decision are the marginal costs of ordering one more unit into inventory versus placing one more purchase order or performing one more setup. Carrying cost, for example, is often considered to be an opportunity cost - the percentage return given up by investing in inventory instead of the best possible alternative investment - plus the cost of having inventory at all. The cost of having inventory, in addition to the opportunity cost, includes handling, moving, storage, counting, insuring, taxes, and risk of obsolescence, spoilage and shrinkage. From a marginal cost point of view this usual method of calculation is very nearly

> correct, since the largest element of carrying cost is the very legitimate opportunity cost, though the other cost elements, such as storage and moving costs, might well be challenged by the marginalists. The resulting marginal cost to carry would still be close to today's most frequent estimates-in the range of 30 to 40% annually of the value of an item.".

In addition he argued that to ask 'What does it cost to place one additional purchase order?' and then to answer by dividing the total purchasing and receiving department's budget into the number of orders placed would be incorrect. The marginal cost of placing one more order should be an extremely small value relative to average cost. The justification for this view is that your current staff are being paid their salaries, the office furniture is there, and the space is allocated whether you place one more order or not. These are sunk costs and are simply not relevant to the lot-sizing decision. The cost of purchase order form itself, of course, should be considered, but not the time to prepare it, because the preparer will be there, on salary, anyway. St. John, concluded that:

> "The allocation of fixed costs is a convenient accounting technique but has no place in decision making - including the determination of lot sizes.".

In more specialised models (where an attempt was made to introduce dynamic elements, in line with the true nature of industrial environments) the list of convenient assumptions grew. They included such assumptions as 'arrival probabilities of the outstanding orders were independent of the number and size the outstanding orders', as well as, 'the true demand in the field to be a random variable with a known distribution function'.

It is suggested that industrialists would greatly appreciate the ability to forecast future demand based on a predictable statistical probability function. However, they recognise that such assumptions rarely apply to the dynamic market conditions under which they operate. The rate of growth in the economy at large and in their particular industry sector, as well as, competitive pressures, effective marketing and advertising are just some examples of variables which influence customer demand most of which are difficult to predict or control. The academician can afford the luxury of convenient assumptions in their equations, the industrialist can not.

With the growth in the use of computers both in academic and industrial environments, the complicated linear programming techniques were applied to the production and inventory control field. The introduction of computers it is argued, added an air of respectability to these techniques which took a long time to shake off. Wagner (1973), wrote:

> "Most linear programming models assume that future demand is known, and therefore must hedge against uncertainty by adding in extra restrictions on minimal inventory levels and maximum production levels. But we have no scientific knowledge about how well such models behave from week to week, or month to month, when they are repeatedly reapplied with updated forecasts. Similarly, most inventory stockage models that treat demand probabilistically assume that the distribution of customer demand is known. In reality, when the operations-research analyst postulates the form of demand distribution, he then must estimate the parameters of the distribution using past data, which introduce further error and uncertainty. And, as the operations researcher periodically reestimates the parameters, the inventory and service levels may behave quite differently than predicted by the original mathematical model in which the demand distribution is assumed to be known.".

The optimum solutions derived from Linear Programming (LP) techniques, however, proved useful in other environments such as optimal yield formulation for animal food production and some forms of investment analysis.

In an attempt to verify their assumption about the nature of a manufacturing plan, the practitioners increasingly resorted to the use of computer simulation models. The concepts of feedback/feed forward were incorporated into forecasting of demand incorporating seasonal fluctuations and trends, Winters (1960). Eilon et al (1970), suggested a method for computing periodwise control limits based on Winter's demand forecasting procedures.

The attraction of EOQ formula, however, proved too much for many researchers, who incorporated EOQ based models in their simulation models, Berry (1971), Gross et al (1971), Packer (1967). Conners et al (1972), constructed a large-scale physical distribution simulation model (DSS). It was designed on the lines of 'Total System Approach'.

3.2.1 LIMITATIONS OF MATHEMATICAL INVENTORY MODELS

The shortcomings of mathematical models in relation to the realities of practical industrial environments will be considered in the following discussions. If one questions the reasons as to why optimal mathematical models are inappropriate tools for use in the industrial environments, the answer it is suggested, lies in the simplistic assumptions which are made. The fact that any complex mathematical equation is more likely to be solved if the constituent elements behave predictably, it could be argued, might have had some influence in these matters. It is therefore conceivable that the assumptions which were made prior to the development of such models had more to do with reducing the number of variables to make the equations easier to solve, than any true study of the nature of production and inventory planning function in industry.

Other shortcoming of these models is that in a dynamic environment, the time scale during which the so called optimum solutions would have been valid, is limited, Aggarwal (1974). The following are the major limitations of their assumptions;

(1) The selling price has been assumed to hold at a constant level over a period of time. To an industrialist this assumption would be ludicrous. Price of a product, could be argued, would be determined by many factors in the market place, not least of which is the scale of the competitive pressures and the particular industries future production and new product plans.

(2) The lead time on production and procurement has generally been either assumed to be constant or zero. This assumption more than any other indicated the inappropriateness of mathematicians creating artificial problem conditions and subsequently formulating a solution to yet an other imaginary inventory control problem..

(3) The demand distribution of individual items has been assumed to be either independent of each other or independent of the selected replenishment policy or both.

(4) In the cases of unbounded planning horizon, the optimal solutions rely on such assumptions as; stable periodic demand distribution and stationary costs. Further more, it is assumed that backordering and shortages are simple elements which can be assumed to have an estimable monetary value. Aggarwal (1974), In a discussion on the limitations of theoretical inventory models wrote:

> "From company to company, even for the same items, the demand patterns, lead time fluctuations, and cost structures are likely to be different. Therefore, for optimising inventory operations, each company needs to compute its specific optimum inventory policy for each of the thousands of items, for the then-existing values of the the respective parameters of that item. As the time passes, the company may find that even for a particular item, the conditions in relation to the demand, the cost elements, the supply, the lead time, etc., have completely changed, and in consequence may conclude that the previously computed policy is not any longer for the current values of the item parameters.. for keeping the inventory operations of a company optimal; the management will have to compute period after period (daily, weekly, monthly) the optimum values of the limits of inventory levels for each of the thousands of the stocked items, and they may even have to use different models for the same item or the family (or group) of items from period to period.".

The more likely scenario would be that management believe what the computer suggests until the next financial crisis, and even if they were to attempt such a proposition to incorporate all the optimising models in a single inventory control system can be an extremely costly proposition. He further pointed out that:

> "If it is assumed that the decision to switch from one policy to another for the same item will be made by company analysts, even then the computer programmes for individual items will have to be updated quite frequently and such a set-up will constantly require the efforts of a large number of analysts and programmers. The costs of such additional personnel will most likely offset the savings resulting from the extra efforts spent on matching the most suitable and optimising inventory policy with each of the items of the system at the beginning of each period."

Some observers, however, began to question the merits of such techniques in the real life environment. Monhemius (1981), quotes practitioners as saying:

> "Solving models instead of problems" and the "Practicality gap".

Many of the ideas developed in this period are, still being used both in educational and industrial environments and operational research journals are still publishing new variations on the EOQ formula for use in industry.

At the same time, Japanese were looking at ways of reducing both work-in-progress and raw material/finished goods stock. Fox (1980), wrote:

> "The concept of safety stocks and economic lot-sizes so common in the West are viewed as undesirable costs rather than benefits by the Japanese. The production of material in excess of current needs, or substantially before it is required, is considered a waste that can not be afforded.".

The Japanese government, in the 1950s, in their quest to increase productivity in the vital manufacturing industries directed their academicians to work with the industrialists to find practical and economically sound solution. He argued that:

> "Japan had virtually no raw materials, a large labour force and a limited national/regional market for modern industrial and consumer products. In order to develop world markets and compete effectively, they have focused heavily on becoming a highly efficient converter. Consequently, they have concentrated on developing materials management systems that both minimise inventory and maximise utilisation of facilities. Specifically, Japanese systems are geared to having the right amount of material at the right location at the correct time. The term 'Just In Time' is used to describe these systems.".

Fox, further pointed out that they aimed to simplify the whole structure of manufacturing systems to minimise uncertainties and stochastic variables, to maximise the return on the investment and to minimise the capital employed in non performing assets:

> "Since inventories and facilities generally represent between 70% and 80% of the assets of a manufacturing company, the the need for effective materials managements management systems will become more acute.".

The issue therefore, rests on the undesirable,'intellectual acceptance', of stock levels in any area where the EOQ formula is applied.

It could of course be argued that by increasing the inventory holding costs, the resultant economic quantity from such models would be reduced, thus leading to smaller lot-sizes for inventory purchases and production batch quantities, however, this approach would further highlight the irrelevance of the EOQ based mathematical models. The obvious conclusion it is argued, would be to abandon these techniques and write off the mistakes of the past and to adopt the evidently more successful Japanese approach of low inventory and Just In Time (JIT) production. St. John (1984), concluded that:

> We are in the midst of a revolutionary period with regard to manufacturing philosophies. We are being driven to achieve shorter lead times, more efficient production processes, more variety in the products we make, and faster response to the needs of our customers. The end result of this progression will demand that we drive lot-size thinking out of our production planning activities. Our competition, particularly from overseas, is forcing such an approach on us at the present time. In addition, there is an irresistible market presence that is driving us to this same conclusion.".

Oliver W. Wight, in a forward written for the book, Distribution Resources Planning, Martin (1983), described the proliferation of statistical inventory techniques in the 1930's. Before computers, he stated:

> "Keeping order points updated was an almost insurmountable task ... We knew that safety stock computations were a guess at best".

The availability of computers to rapidly and economically manipulate the data for exponential smoothing and mean absolute deviation to compute safety stocks statistically. Wight, wrote:

> ".. seemed like the answers to our problems.".

In the early 1960s the IBM developed software, called IMS (Inventory Management Simulator), was implemented at the Stanley

Works. Wight, recalled:

> "The results were very good, but a couple of nagging questions began to concern me. Jim Harty (now the president of the Raymond Corporation) observed, 'I think you really accomplished more with the production planning that you introduced rather than the exponential smoothing.' Like most enthusiastic supporters of the operations research techniques, we tended to give a lot of credit to the fancy formulas. We had simultaneously changed the approach from simply having an inventory control system dump orders onto a factory, to having the inventory system feed orders in at a rate that was regulated by a production plan. Could this have really given us the bulk of the benefits?".

Orlikey (1975), back in 1966 when working for IBM expounded the 'independent / dependent' demand principle: Order point can be used on independent demand, but material requirements planning must be used for dependent demand items. He further endorsed the concept when he wrote:

> "As MRP became more and more popular, my experience with it was far more satisfactory. It worked every time. There was a direct causal relationship.".

The regressive culmination of mathematical modelling as an aid to management was best summed up by Wight, in the following paragraph:

> "I have always found it somewhat ironic that those who have promoted the 'quantitative, mathematical, analytical ' approaches call this scientific inventory management or management science. The scientific method says that one must observe, hypothesise, apply the hypothesis, and find out if it works; and if it doesn't, modify it until such time as it does. When people have forgotten the basic principle of the scientific method, and assume that anything mathematical and analytic is, by definition, 'science', they violate the very meaning of the word.".

The key conclusion to be drawn from the above discussions is that there is considerable body of knowledge that regard the use of EOQ type mathematical models for the determination of inventory levels in manufacturing organisations as wholly inappropriate. The phenomenal growth of the Japanese industrial sector since the inappropriateness of mathematical models as tools for determination of inventory and batch quantities in the manufacturing industries.

3.3 DEVELOPMENT OF FEED FORWARD DETERMINISTIC SYSTEMS

The belief in the usefulness of mathematical models in practical industrial environments had to end some time, and by the end of 1960s some of the practitioners in the field of production and inventory management were beginning to voice dissent, it took some time before their views filtered through to some of the text books and in sufficient numbers in the relevant professional journals, but it happened. Wagner (1974), in a paper published in the Operations Research Journal wrote:

> ".. the production and inventory systems designer for the kind of firm that I have described can get only limited help from the available scientific literature...".

The building of more sophisticated models for problems which are remotely related to those which decision makers in production and inventory control area face, showed some signs of slowing down. Wagner wrote:

> "It is paradoxical then, that so few of these techniques have been implemented in real manufacturing companies.".

A clear synthesis of knowledge was being asked for and to a large extent the move towards real problem solving was established. The development and expansion of literature on Material Requirements Planning, (MRP) was one such breakthrough. Orlicky (1975), wrote:

> "The inventory problem was perceived as being essentially mathematical, rather than one massive data handling and data

> manipulation, the means for which simply did not exist in the past. The fact, that the chronic problems of manufacturing inventory management are now being solved , however, is due not to better mathematics but to better data processing.".

The deterministic thinking and adoption of the feedback/feed forward concepts mentioned earlier began to play an important role in a move towards real problem solving. Many accepted forms of wisdom about the nature of the manufacturing organisation were discarded and the word 'random' was used sparingly. Orlicky, wrote:

> "Dependent demand need not, and should not, be forecast, as it can be precisely determined from the demand for those items that are its sole cause.".

With the development of the logical deterministic MRP technique, the opportunity for the Western industrialised nations to adopt a low inventory approach to manufacturing, became plausible. The degree to which this opportunity was successfully exploited after the development of computerised MRP systems, will be discussed in the following chapters.

3.4 CONCLUDING REMARKS

The above discussions highlight the background arguments against the use of mathematical modelling techniques in the design and operation of practical production planning and control systems in manufacturing industries. It is not suggested that mathematical modelling techniques in themselves are totally worthless, it is however, suggested that these techniques encourage the view that inventories are an inevitable feature of manufacturing organisations. In this context therefore, not only are they worthless, but a positive handicap to gaining competitive advantage in the global markets.

CHAPTER 4 THE DOMINANT PRODUCTION AND INVENTORY CONTROL SYSTEMS

This chapter will discuss in detail the characteristics of the main production and inventory planning and control systems. The discussions will explore the development backgrounds as well as individual methodologies of MRP, JIT and OPT . The advantages and disadvantages of each approach will also be highlighted.

4.1 THE DEVELOPMENT OF THE MRP II SYSTEM

The deterministic approach to production planning and control problems, started in 1926 with the development by Gigli, of Period Batch Control, Burbidge (1971). Monhemiuos (1981) , described it as:

> "An early version of MRP with special form of lot sizing.".

This system started the gradual departure from the use of the discredited mathematical modelling approach to production and inventory control problems The EOQ formula based systems, however, were the dominant form of planning in the Western industrialised countries, up to the late 1960s. Todd (1987), one of the founding fathers of the American Production and Inventory Control Society (APICS), wrote:

> "There are many problems with the EOQ formula, but the chief one was that it was the only concept in the vast array of statistics that totally look backward as a means of predicting the future. A scheme to plan for horseshoes would not itself create a demand for horseshoes. ... In the 1960s, an improved concept was instituted. This was the totally logical thought that the manufacturer should plan what he was going to produce in the future, and when, and then order the required components, whether produced internally or purchased from outside sources, accordingly. To be workable, this concept required that the forward planning extended out just as far as the longest lead time

required for production or purchase of components.".

This was the beginnings of the Material Requirements Planning (MRP) approach. This simple and logical approach, it is suggested, was soon handicapped by the EOQ formula exponents, who introduced numerous static and dynamic batch sizing rules both into the basic MRP methodology. The potential for a more wide spread adoption of make to order or lot for lot manufacturing culture was lost. Soon after the early versions of the MRP systems were developed, operational research journals started to publish articles on the suitability of EOQ formula for determining optimum lot sizes of both manufactured and purchased items.

St. John (1984), in an article in the American Production and Inventory Control Society (APICS) journal wrote:

> "Looking back on the last two years of published articles in the field of production and inventory control, particularly with regard to MRP, it is quite remarkable that we continue to be inundated by the subject of lot sizing. Wagner-Whitin, part period balancing, EOQ, period order quantity, least unit cost, Silver-Meal (and its many derivatives) still seem to be 'hot' topics in our attempts to optimise the production and inventory planning functions of MRP. And how inappropriate is this passion for lot sizing evaluation when the creation of cycle inventories is the very antithesis of the society's Zero Inventory Crusade! Lot sizing creates inventory, it does not eliminate inventory.".

Clearly the opportunity for the creation of a radical new manufacturing planning and control philosophy, which embraced low inventory, small batch sizes, just-in-time production and procurement, was lost. Looking at the growth of the imports from Japan, over the last two decades, it is suggested is sufficient justification for concluding that the approach was wrong. St. John, further wrote:

> "Since around 1960, when a few of us pioneered the development and installation of computer-based MRP systems,

> time-phased material requirements planning has come a long way; as a technique,as an approach, as an area of new knowledge. ".

In the early 1970s, following an unprecedented set of coordinated campaigns in U.S.A., and Europe, involving professional bodies like APICS and BPICS and most of the major computer manufacturers, material requirement planning became the dominant system for production and inventory control.

This initial crusade, by the late 1970s led to the development of an integrated production planning and control system incorporating the manufacturing, marketing, sales and finance departments which by reverse anagram was called manufacturing resource planning, MRP II.

4.1.1 THE MRP II METHODOLOGY

Material requirement planning and its enhanced derivative, manufacturing resources planning, have provided the computerised management information data structures which have lead to the development of the integrated manufacturing planning and control philosophy.

The basic MRP system is a time-phased order release system that attempts to schedule the release of orders for the dependent demand inventory items in a just-in-time manner. i.e., the arrival of components of manufactured parts as near as possible to the time when they are required, and not significantly earlier. The system comprises of the following central modules:

- Master Production Schedule (MPS)
- Bill Of Material (BOM)
- Inventory Status (IS)

The MPS contains the period to period requirements for the end items of the operation. The data is typically derived from actual firm customer orders and forecasts of potential demand in the future, figure (4.1).

The BOM module contains the specific descriptions, provided by the engineering functions, of the component parts required for each end item and their relationships, in the process of manufacture, to the end item and each other.

The IS module contains the inventory status of all the components and end items, including the unfinished items which are expected to be completed within each planning period. The accurate maintenance of data rests with production and inventory planning functions. Without accurate information the total systems output would rapidly degenerate. MRP system are either regenerative or net change. However, as Orlicky (1975), pointed out:

> "A given regenerative system may have 'borrowed' some features of a net change system; conversely, a net change system may be used the way a regenerative system is intended to be used.".

In regenerative systems, all requirements are exploded in one batch-processing run, as the master production schedule is periodically being changed. During this run, the gross and net requirements for each inventory item are recomputed and its planned order release schedule is recreated. This process is carried out in a level by level fashion, starting with the highest product level and progressing down to the lowest (purchased material) level.

Schedule regeneration relies mostly on sequential data-processing techniques, and is a batch processing method that is very data intensive. Each regeneration (explosion) represents a replanning of requirements and an updating of inventory status for all items. Intervening changes in the MPS, BOM or any of the planning factors, are accumulated for processing in the next regeneration. The function that the requirement planning run provides is essential for the maintenance of system integrity, however, the interval between runs can be stretched out. Net change material requirements planning manifests itself through consecutive, partial explosions performed with high frequency, in substitution for a full explosion performed periodically at relatively long intervals. The partial explosion is the key to the practicability of the net change approach, as it minimises the scope of the requirements planning job at any one time and thus permits frequent replanning. The partial explosion limits the volume of resulting output. Under the net change approach, the explosion is partial in two respects:

(1) Only part of the MPS is subject to explosion at any one time.
(2) The effect of transaction triggered explosions is limited to lower level components of the item providing the stimulus for the explosion. The operational characteristics of MRP II systems will form the basis of the following discussions.

4.1.2 CHARACTERISTICS OF MRP II SYSTEMS

Figure (4.2), represents ideal MRP II operational methodology. Exception reports are generated if the ability to achieve requirements is for some reason impaired. The literature suggests however, that

MRP II PLANNING LOOP

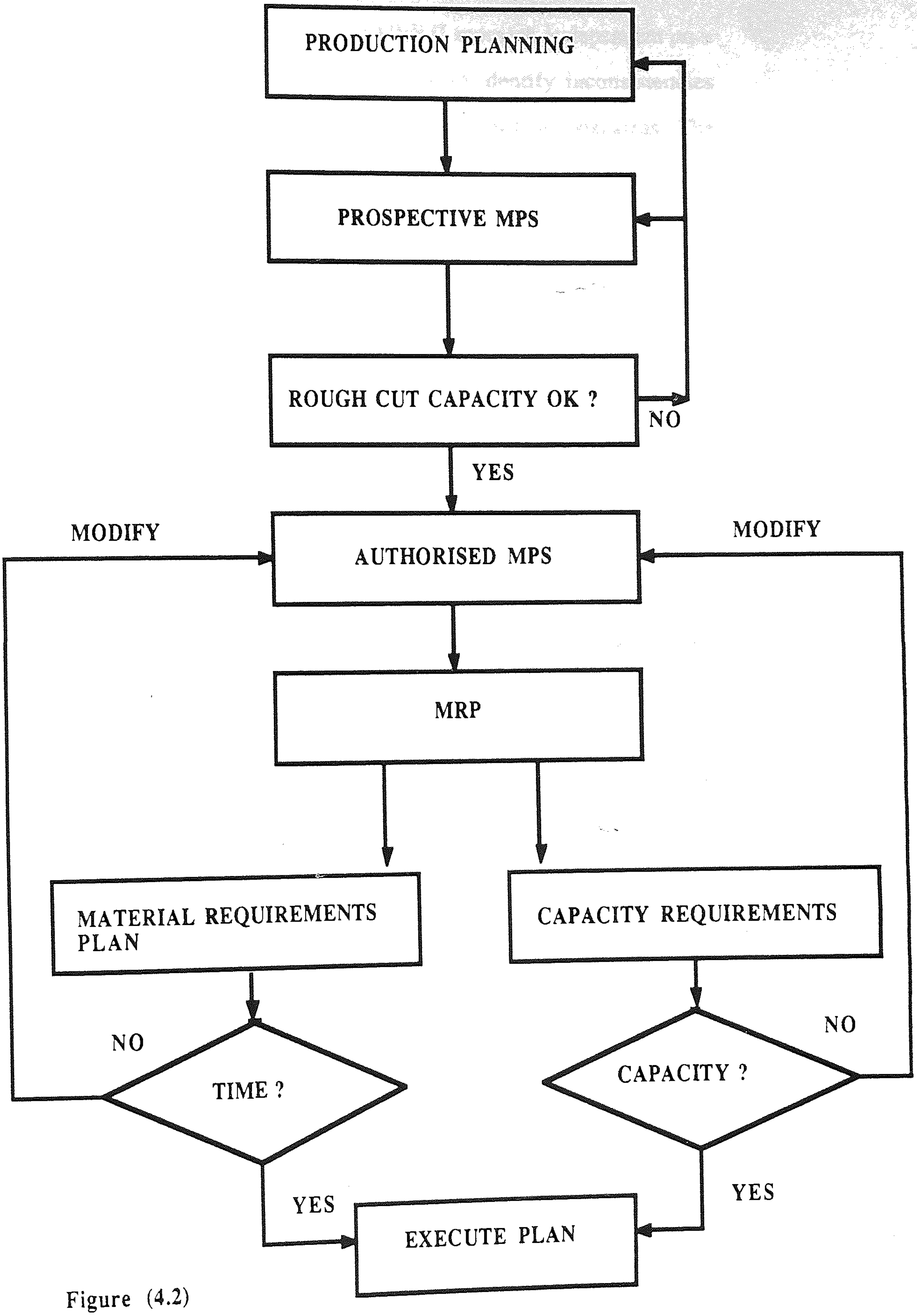


Figure (4.2)

the ideal practice, has proved difficult to implement. The mechanism of the closed loop MRP II approach is dependent on a series of procedures which attempt to identify inconsistencies present between manufacturing and the other functional areas. The goal of the MRP II process is to achieve a valid MPS. The capacity inconsistencies are supposed to be ironed out by following the iterative processes. The load profiles resulting from Rough Cut Capacity Planning (RCCP) are used to adjust overloads and underloads to arrive at a production plan that considers both market requirements and capacity constraints. This gross level process deals with product families (not individual items), key production areas and time frames of months or even quarters, Fox (1983). However, RCCP assumes the plant is empty, ignores work in progress and it assumes that all the parts, subassemblies, and final assemblies can be made in the period they are demanded. It also ignores the batching or lot sizing of production which occurs in most plants. These simplifying assumptions are made to reduce an otherwise prohibitive computer processing time. The resultant production plan is then converted into a master schedule by translating the family groupings into individual items. The time frame is also refined into weekly requirements or specified due dates.

The second iterative phase starts with an MRP run which explodes the master schedule into its subassembly, component parts and raw material requirements. These requirements are offset by predetermined lead times (often grossly inflated, bearing little relation to the actual set up and process time of a product). This is due to the capacity insensitivity of the methodology. The companies therefore, have to plan for the worst case. The common requirements are aggregated at each level of product structure and then netted against any available inventory. Lot sizing rules are applied to these net requirements. The result is a requirements schedule for all levels of product structure subassemblies, component parts and raw materials. These requirement schedules are back scheduled from their due dates so that load profiles can be generated for the machines and manufacturing processes required by these schedules. This is called Capacity Requirements Planning (CRP). The master scheduler is then supposed to review the load profiles and make adjustments in the master schedule to resolve any overload or underload conditions that may exist. However, as Fox (1983), pointed out:

> "In reality, the master scheduler seldom has the opportunity to make adjustments in the master schedule. The computer time required for an mrp-CRP run is so extensive that only one run is usually made each week... we do not have the luxury of unlimited computer time. This is the reason the rough cut capacity planning process was developed. We needed a short cut, even if it had simplifying assumptions, to incorporate capacity limitations into our master schedule.".

Apart from practical difficulties of running a plant in accord with the ideal operational methodology, the use of fixed predetermined lead times by MRP systems further discredit the schedules on the shopfloor, since they bear no relation to the actual start and finish times of the works orders. This is due to the incorporation of as much as 90% slack on top of the actual technological lead time of the planned orders (set up time+ batch quantity * unit process time) at each stage of the manufacture, to compensate for the overloads and underload which occur on the shopfloor. In practice therefore, most plants simply use their MRP II systems in the same manner as the earlier MRP systems. The addition of financial and payroll modules in the MRP II systems, have tended to further limit the computer time available for 'what if' analysis. The centralised structure and the concentration of data into a single data base itself has imposed constraints on the ability of industrial organisations to make the most of their expensive software/hardware investments. The above briefly discussed the difficulties encountered in achieving a closed loop MRP II operational status, the following have discussed the above and other characteristics of the MRP/MRP II systems in more detail. Barekat (1984), Proud (1981), Putnam (1983), Miller et al (1975), Thompson (1983), Boyer (1977), Fisher (1980).

4.1.2.1 POTENTIAL BENEFITS OF MRP SYSTEMS

The benefits derived from the implementation of an MRP system, clearly depend on the degrees of success in the implementation. Computerised databases allow planning, co-ordination and integration of information and, given a total transformation of informal practices into a formal regime, the opportunity for cooperative interaction between departments. Figure(4.3), summarises the main changes which could be expected of a successful MRP II system implementation.

Reduced inventory investment, increased inventory turn around and improved customer service levels are the main advantages cited by the successful users of MRP II, Woolcock (1984), Melnyk et al (1985).

Increased levels of customer service also rank high amongst post implementation studies of most organisations who have successfully implemented an MRP II system. The improvements generally result

SUMMARY OF FORMAL CHANGES AS A RESULT OF A SUCCESSFUL MRP II IMPLEMENTATION

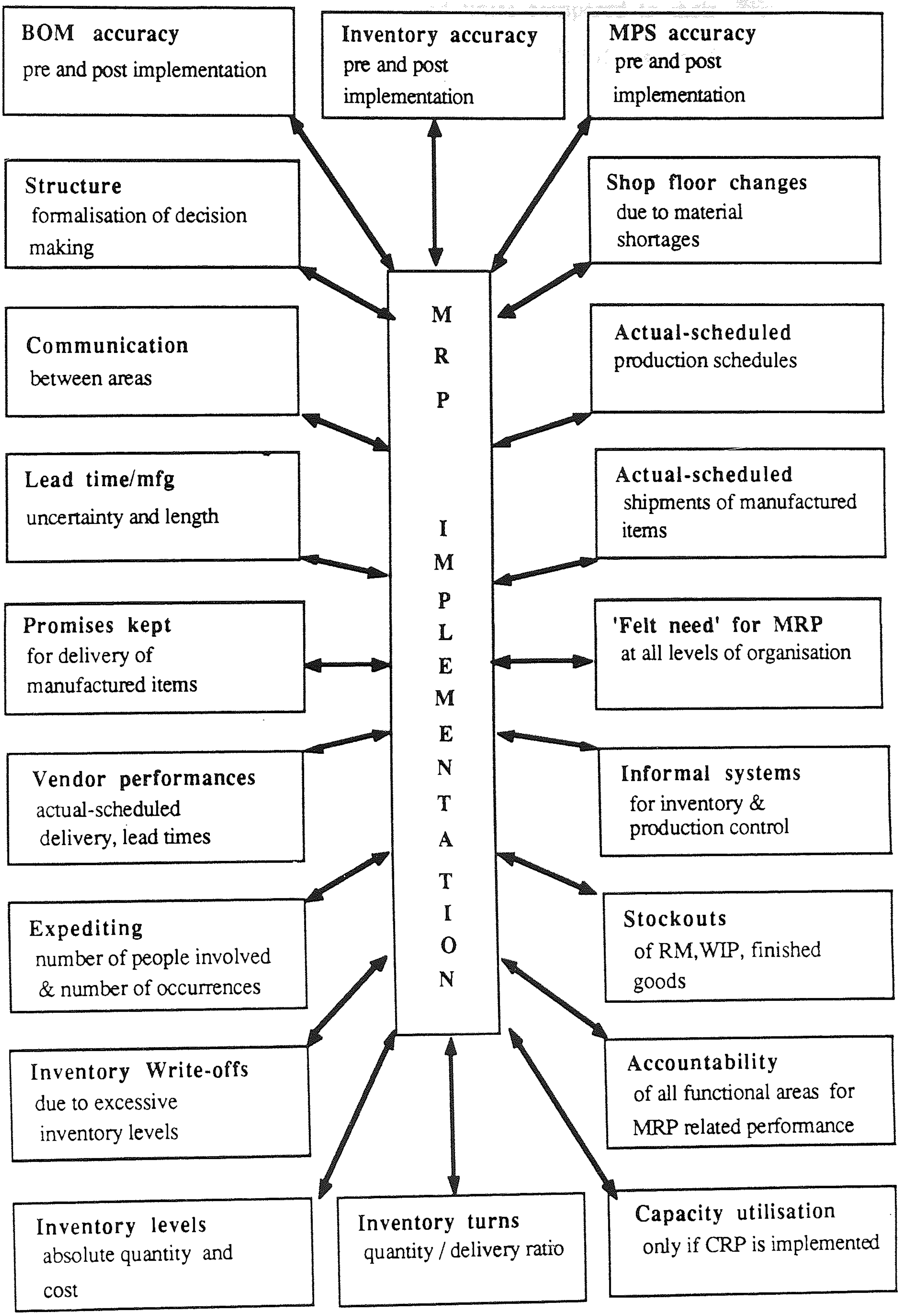


Figure (4.3)

from a reduction in the back orders, increased number of timely deliveries and reduced supply lead times compared to their performance when they did not operate under MRP II system of planning and control.

Clearly, organisations evaluate the advantages of MRP II implementation relative to their performance prior to implementation. It is suggested that, since the MRP II systems, at their operational level, impose a much needed formal discipline on badly organised and largely informally run manufacturing companies, those companies obtain great benefits from the switch over to the formal procedures in the short term. However, in a competitive manufacturing environment the achievement of further performance improvements tend to be limited by the logistical shortcomings of concentrating the total data processing and data management into a centralised computing structure. Kruse (1987), in a fundamental review of the role of MRP II wrote:

> "MRP was an innovative approach to bring order into chaos, and whilst it had many shortcomings, it provided for the first time the practical tools to effectively manage large amounts of data without falling back on unsound, oversimplified statistical techniques."

Figure (4.4), shows the triangle conflict which a successful MRP II implementation is supposed to resolve.

A further positive consequence of the formalised approach to organisational planning, which is a prerequisite for successful implementation of MRP II systems, is the ability to introduce, additional computer aided decision making tools across the whole range of company functions, and when appropriate, the eventual adoption of computer integrated manufacturing (CIM) philosophy. The difficulties of implementing an MRP II system in industry will be discussed next.

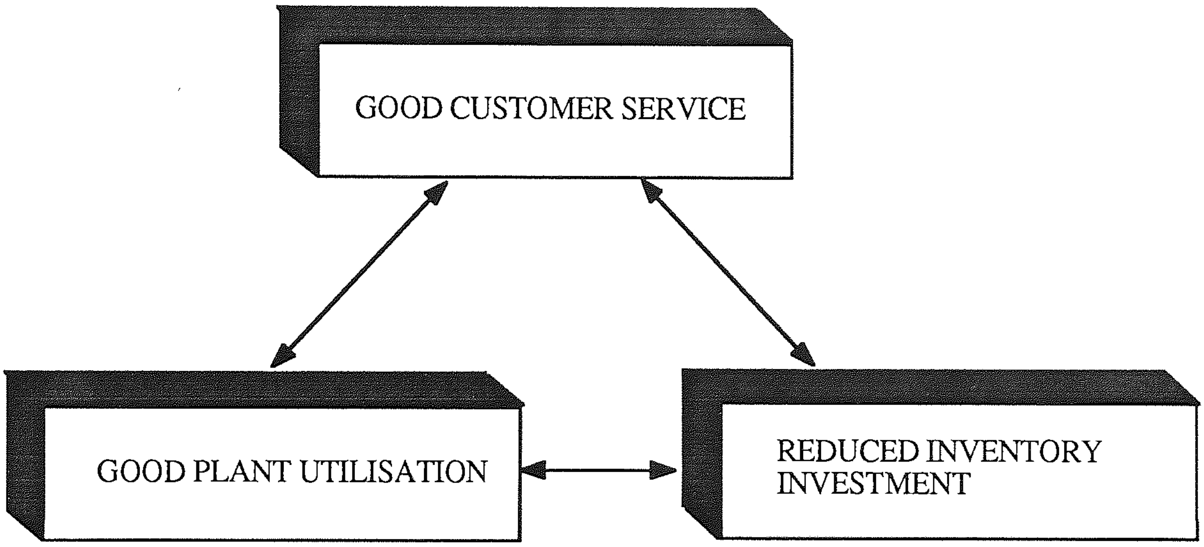

THE TRIANGLE OF CONFLICT

Figure (4.4)

4.1.2.2 DIFFICULTIES IN IMPLEMENTING AN MRP II SYSTEM

The number of MRP II users which have succeeded in implementing the total closed loop approach, has remained low as a proportion of the total implementations. It has been estimated that the unsuccessful implementations (however defined) do outnumber the successful cases, by a wide margin, White (1986).

Various studies into the causes of such failures have been carried out both in the U.S.A. and in Europe, and presented in the professional journals of organisations such as APICS. The following cover most aspects of difficulties in implementation; Beal (1979), Blasingame et al (1981), Etienne (1983), Fisher (1980), Hay (1978), Rose (1978) and Wacker et al (1977).

Blasingame et al, in a study of the reasons for the relatively high number of unsuccessful MRP II implementations concluded:

> "Organisations appear to differ widely in their capacity to implement MRP. However, even under the most favourable circumstances the MRP change is likely to encounter some resistance and behavioral problems.".

The project management and educational prerequisites, relating to successful implementation of a company-wide MRP II system, have been discussed by the author, Barekat (1984).

The practitioners, it is suggested, are divided into two broad categories with distinct views about the reasons why most MRP II implementations have not been totally successful . The first group, have accepted the validity and appropriateness of MRP II systems as they currently operate, but believe the reasons for the high rate of failures in the implementation of such systems, are either bad project management and general resistance to change or lack of pre and post implementation, education or both, Roberts (1982), Inness (1980a),Inness (1980b), Wight (1983), Wight (1984), Houlihan (1982), Cleator (1979), Swan (1983), Rice et al (1980), Ruddle (1978), Benedick (1983), Hartley (1983), Blumberg (1980).

They would argue that the research has shown the majority of MRP II implementations have not fully yielded the returns that were anticipated. Since the technical aspects of MRP II systems are easy to understand, it must be concluded that the problems are people-related. Successful implementation requires a total change in the corporate culture, in relation to its personnel, responsibilities, processes and the way the organisation views and interacts with its external environment. The users must understand and accept the system as an improvement to their existing methods, if the implementation is to succeed. The necessary ingredients for success are good management support, involvement of the users, education, sound design, execution of key tasks such as maintenance of bills of material, and inventory status files. Their views could be summed up in this manner; the MRP II systems are inherently sound however, the people tend do the wrong things at various stages of implementation or operation or both, thus leading to unsuccessful MRP II implementations.

The second group, accept the major contributions of the MRP methodology in providing a simple deterministic philosophy of inventory planning and control, to supercede the discredited mathematical modelling techniques. They also recognise the importance of the structured data bases (which were necessary to make MRP a reality), in providing a stepping stone for further technological and philosophical developments in this field. However, whilst recognising the necessity of issues relating to professional project management, they would argue that the MRP methodology, as it stands, has basic inherent weaknesses which make the task of implementing and successfully operating the system, very difficult. This group have set about evaluating and developing alternative approaches to the existing MRP II systems, which build on their strengths. These include, Goldratt (1981), Goldratt et al (1984), Fox (1982), Fox (1983a), Fox (1983b), Wheatley (1986), Parnaby (1987), Plenert et al (1986), Lundrigan (1986), Swan (1986), Vollmann (1986), Booth (1986), Hill et al (1986), Levy (1986), Love et al (1988).

They argue that even with competent and educated management, the returns from an MRP II system implementation tend to be, generally less than anticipated. White (1986), wrote:

> "During the last ten years, thousands of manufacturing companies have implemented many of the latest techniques contained in material requirements planning (MRP) systems. Several are spending significant time and money 'running MRP,' but they are not achieving the hoped-for results. Although a growing list of firms have reduced inventories by 20 to 40 %, improved efficiencies by 5 to 20 %, and improved customer service by 10 to 50 %, most companies have not realised these kinds of benefits.".

Employees resistance to change, lack of MRP related education or bad project management are the main reasons for lack of success stated in the literature, however, a large part of the difficulties in successfully implementing an MRP II system can be shown to be as a result of its shortcomings. Lundrigan (1986), wrote:

> "MRP has reached its adolescence. We hate to do so, but having invested a lot of time and money in making it work, we're forced now to admit that there are some things wrong... Some of the fault may lie with us, but more frequently than not it lies with MRP. In any event, it's time we took a fond but candid look at MRP - not with the aim of dwelling in its shortcomings, but with an eye toward realising the fullness of its potential....MRP is not dead, nor is it dying. It just needs some help... What is needed is MRP plus a redirection of manufacturing practices.".

Conventional manufacturing control systems adopt a centralised approach to the planning process. This is especially evident in Manufacturing Resource Planning (MRP II) systems in which a single system (and computers) is used to plan and control most manufacturing related activity within a plant. All the relevant information is held within a vast and highly complex database and maintained by an equally huge number of transactions which must all be processed by the host computer. The system software must be able to fulfil the needs of all the different manufacturing related activities within the plant and must therefore, offer a broad range of facilities and options which serve to continually increase the complexity of the system. Such systems inevitably become difficult to manage effectively. Accuracy of data is also of of prime importance if the system is to generate realistic and effective action reports. Maintaining adequate levels of accuracy in bill of materials, routings and inventory data is especially difficult in large systems. Apart from the logistical considerations of running an MRP II system, capacity insensitiveness is the major flaw of the methodology.

MRP II systems utilise predetermined lead times in the scheduling of the work orders. This method is inherently unsound, since lead times can only be derived from the way the schedule is constructed. In practice the lead time for an item is composed of three elements; setup time, process time and slack time. The use of large slack times are an arbitrary, yet necessary consequence of the capacity insensitiveness of the MRP methodology. Slack, which according to Fox (1983), can be as much as 99% of the lead time, is the extra time added to the true technological lead time (setup + quantity * unit process time), primarily because the MRP schedule will result in overload and underload conditions on the shopfloor. This extra time allows the people on the shop floor to make adjustments in the MRP schedule to conform to the reality of the transient capacity conditions on the shopfloor. It is also justified as necessary flexibility to account for the time needed to transfer batches between operations.

It is not therefore, difficult to see why the suggested order release dates are generally ignored by the shop floor personnel, leading to a gradual return to the informal mechanisms of the past and yet another unsuccessful MRP II implementation.

The top-down planning and the centralised structure of the MRP II systems, imposes this mode of operation upon the shop floor. A further consequence of the use of inflated fixed lead times is increased work in progress levels (MRP logic assumes that batches are transferred between operations once the whole batch has been processed).

An experienced shopfloor manager would find this condition unsatisfactory. However, to ensure compliance with the formal MRP methodology the manager is discouraged from taking decisions based on the local shop floor conditions. In practice however, plant managers tend to disregard the suggested start and end dates for the work orders which in turn leads to lack of effective control over the manufacturing operations and the gradual deterioration of the overall system.

Any control system which does not provide sufficient flexibility and does not adequately support realistic plant level production planning and control activities, would inevitably be disregarded by the shopfloor managers. Since most MRP II system implementations fail to meet original expectations prior to their implementation, they fall into the above category.

A further limitation of the centralised concept of the MRP II computing and database, is in the practical difficulties of maintenance of accurate and up to date data across a whole range of functional areas. This is partly due to the remoteness of database and the lack of ownership and control which is inevitably felt by the departmental managers, when a wide range of personnel could access and even alter important data with ease. The use of restricted access passwords and logging their changes which is sometimes applied as a solution to this problem in itself can further complicate and add to the data processing burden of the conventional systems.

It is suggested that the system's inertia, due to the concentration of computational tasks on a single computer, does not allow for quick response to transient events on the shop floor.

The whole system architecture, results in the MRP systems rarely reflecting the true nature of plant activity. In particular planning based on transient loading conditions of the plant is difficult to implement, therefore, bottleneck planning can not easily be incorporated into the routine planning runs. The centralised characteristics of the system, leads to further negative consequences:

(1) the systems are often perceived as an extension of DP department's activities, which the shop floor personnel have to respond to;
(2) lack of ownership and control over the system, in turn leads to apathy and thus;
(3) lack of motivation to maintain data accuracy of bill of materials, routings, engineering changes and inventory status.

A more responsive approach to planning and control, it is suggested, is needed to resolve this unsatisfactory approach to the management of manufacturing operations, (see chapter 7).

4.1.2.3 TRENDS IN THE DEVELOPMENT OF MRP II SYSTEMS

The potential benefits of the system over the informal approaches of the past, has maintained the trend towards the implementation of such systems. Melnyk et al (1982), wrote:

> "For those who successfully adopt this system it is not simply a planning and control system it is a corporate way of life.".

A delphi study involving a number of APICS fellows, Benson et al (1982), concluded that:

> "The panelists expect the popularity of MRP systems will continue to grow at a rapid pace. They further predicted that by the late 1980s, two-third of all manufacturing companies will have MRP systems; "These systems will tend to be net change, closed loop , infinite loading systems that interface with strategic planning as well as financial systems. ".

The evolutionary developments of the MRP systems are continuing in line with the computer integrated manufacturing (CIM) systems. Owen (1985), describes the evolution of the MRP systems in this context:

> "Twenty years ago companies started moving from simple stock reordering to MRP, making use of bill of materials in full. This gradually extended to take in routings, capacity planning and shopfloor control and eventually became known as MRP II, also incorporating such features as MPS. We are now in the throes of the next big step forward, but as yet not many companies have successfully integrated design or manufacturing technology with MRP II. ".

The MRP II approach can be implemented in a diverse range of industrial environments providing a formal frame work for the introduction of further computerised tools to potentially improve productivity. The introduction of computer aided design and computer aided manufacturing (CAD/CAM), for example, could be greatly simplified if an MRP II system (with accurate BOM , inventory status and routings data) is already operational. Belt (1985), in a discussion of future manufacturing planning and control systems, wrote:

> "They will be built around MRP which is the only true company-wide system that really works. All kanban applications are only partial ones.".

It is suggested that manufacturing functions, should as far as possible, plan their production and procurement activities based on the available data relating to current plant activity. MRP systems therefore, will have to be further evolved in a way which significantly overcomes the inherent weaknesses of the existing methodology and the practical limitations of centralised control.

4.2 THE DEVELOPMENT OF THE JAPANESE JUST IN TIME/KANBAN SYSTEM

The Japanese Just in time philosophy and the related techniques, have been discussed in the literature, Ingersol Eng (1984a), Ingersol Eng (1984b), Fox (1982), Laing et al (1984), Hartley (1977), Goddard (1982), William (1985), Haung et al (1982), Rice et al (1982), Schroer et al (1985), Southern (1985), Sumner et al (1984), Haynsworth (1984) and Manoocheri (1985), Kepmpa (1986), Dreyfuss (1986), Schonberger (1982).

The rapid rise of the Japanese as a major manufacturing country, and their virtual world-wide domination of consumer durables, and, if current trends continue, the automobile industry, has highlighted the weaknesses of the western manufacturing culture, in effectively competing in the world markets. Kempa (1986), in a discussion on the apparent complacency of domestic industries and oblivion to the outside world wrote:

> "Much of this has been attributed to a general failure to respond to the opening of world markets (due to improving communications) and failure to accept the reality implied by the opening of the hitherto closed manufacturing systems called 'Colonial Empires'. Thus many Western industries have found themselves with anachronistic attitudes and techniques, while many Eastern industries (principally in Japan and latterly Taiwan) have seized the opportunity of adopting and developing to meet modern market requirements.".

it would however, be misleading to single out the basic control mechanism of the Japanese, just-in-time (JIT) or Kanban systems, for Japans gargantuan economic prosperity. In Japan, the management philosophy comprises of a set of values and techniques, one of which is the JIT philosophy of manufacture. The JIT techniques are the micro elements of the enlightened, macro view of social enterprises.

This distinction implies that an organisation is free to adopt any element of the Japanese macro enterprise culture, in any environment. The success however, would depend on the competence of the organisation to naturalise those elements into the local environment.

Bird (1983), of the Sanno Institute of Business Administration, in a paper comparing the Japanese and Western management attitudes highlighted Professor Takamiya's model of the divergence in perceptions of enterprise in the following manner:

> "Western managers view the enterprise as a mechanistic object while Japanese managers view it as organic. In the former view, various components are viewed as separable units, the adjustment and regulation of which provide the whole with direction and productivity. Under the latter view, the enterprise is an 'organic human group...a living entity, possessing history and soul.' In the former, labour is a component to be manipulated; in the latter, it is considered as part of the body to be handled with care and accorded respect for the function that it performs. In the West the the relationship is essentially adversarial... In essence, whether conscious or not, labour has likewise developed a view of itself which is mechanistic. .. The workers are like so many spark plugs which work in any engine whether it be Ford, Chevrolet, or Chrysler.".

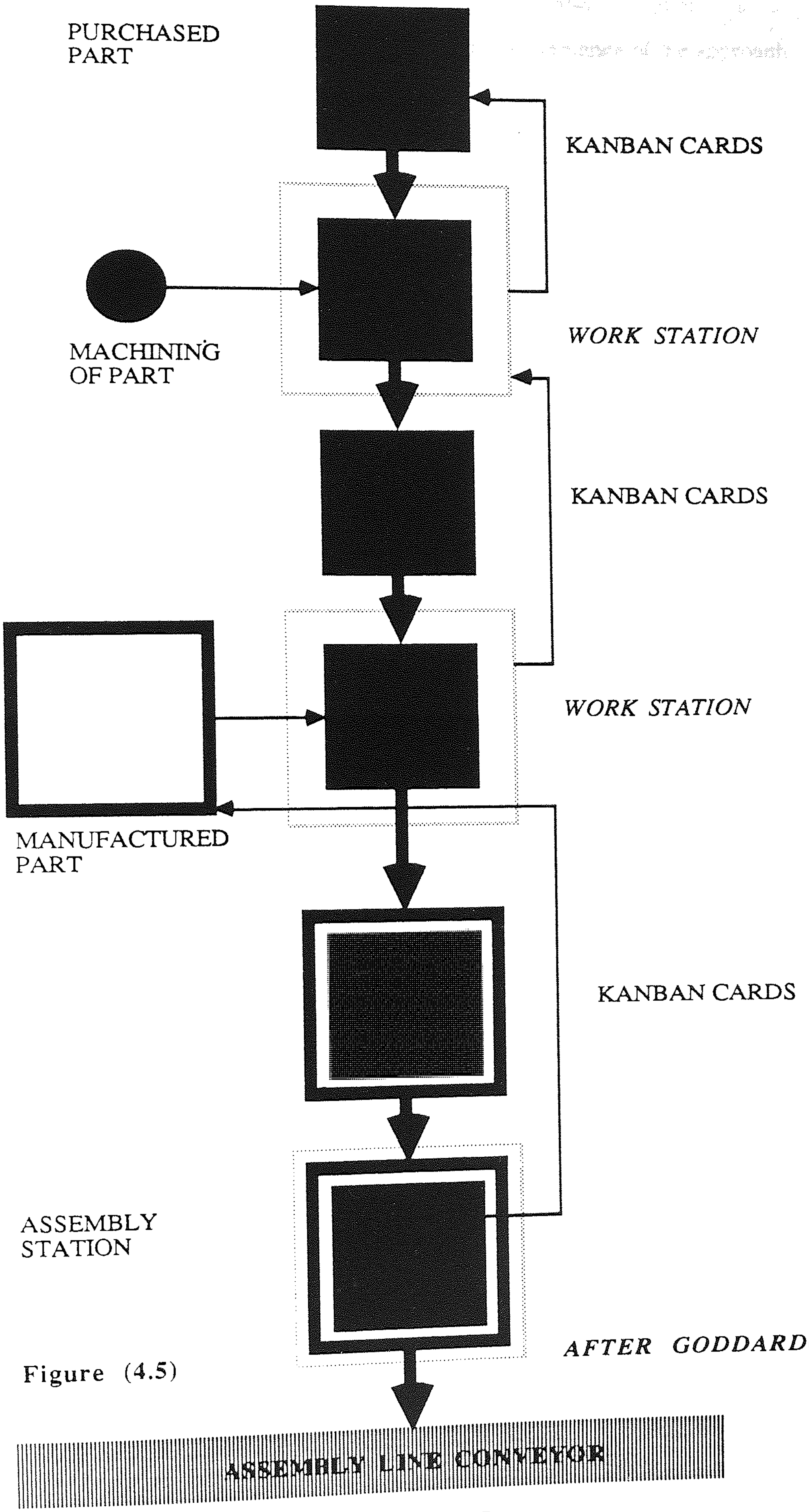
The discussion above are necessarily a brief reference to the importance of other philosophical and cultural view points, which over the last thirty years have been recognised to have had an impact on the relative success of the Japanese industries. However, detailed analysis of such issues regrettably, are not within the remit of this thesis. The issues relating to to the Japanese style of management have been discussed in the literature, notably; Antos et al (1981), Drucker (1981), Johnson et al (1974), Kraar (1975), Ouchi (1981), Ozawa (1980), Clutterbuck (1978), Justis (1981).

4.2.1 THE KANBAN METHODOLOGY

Figure (4.5), shows a typical kanban layout. Goddard, summarises the procedures involved as well as many:

> "Constant replenishment of materials is achieved in a kanban system through the use of two types of kanban cards. A requisition card authorises withdrawal of materials from the feeding operation; a production card authorises the feeding operation to produce more of what is being withdrawn. Once a component is depleted from the final assembly line, that triggers the replenishment cycle, top to bottom. The relationship between the user and a vendor should be the same as the relationship within the factory - small lot sizes, frequent replenishment.".

A TYPICAL KANBAN LAYOUT



AFTER GODDARD(1982)

Figure (4.5)

Finch et al (1986), also highlighted the convenience of the approach:

> "Kanban translates into 'visible record', and a card in not its only feasible form. In some situations, the most convenient visible record is the container itself, an empty container authorising the production of parts. The amount of WIP inventory is then controlled by the number of containers in the system. This approach is similar to that used in a basic 'two-bin' inventory system. Standardised small containers make such a system efficient, visible and easily controlled.".

In a highly repetitive manufacturing environment, the kanban systems have performed well, and a number of companies in the west have implemented such systems and report dramatic improvements in inventory turnaround, reduced work in progress, increased productivity, higher quality products and overall profitability, Kempa et al (1986), Finch et al (1986), Hartley (1977).

The Toyota kanban system has been been discussed by, Monden (1981a), Monden (1981b), Sugimori et al (1977). The overall benefits mentioned above are in many respects identical to those reported by the successful MRP II users. Both systems aim to aid manufacturing companies to effectively plan and control the critical stages of manufacturing. Although MRP and kanban are essentially both JIT systems, the techniques and procedures used to control the production processes are different; furthermore, the MRP II as a computerised system can work equally well for companies with highly engineered, small batch, and one off products, to companies with finished to order, or make to stock products. Krajewski et al (1981), wrote:

> "The Just-in-time system, in the proper environment, reduces inventory investment dramatically,... however the just-in-time system requires a stable master production schedule and, coupled with machine grouping and small lot production,

> produces a daily production schedule which only infrequently changes. Forward planning of component production as in MRP is not as critical since it is relatively stable on a day-to-day basis. Of course products which do not have a large annual demand or are produced to customer order are difficult to incorporate into the just-in-time system."

4.2.2 ELEMENTS OF JIT/KANBAN SYSTEMS

The JIT philosophy consists of a series of broad commandments which can, partially or in full, be applied to a wide variety of manufacturing environments. Increasingly, some practitioners argue that the West should adopt the basic philosophy in a way which suits its industrial culture and environments in the same way, that the Japanese imported Western techniques and knowhow during the reconstruction period, and tailored them to their own circumstances and needs, Rice (1982).

Kempa (1986), Huang et al (1982), Haynsworth (1984), Finch etal (1986) Kim (1985) and Krajewski et al (1981) have discussed the objectives and elements of a JIT system in detail. The following discussions briefly list the elements which have a major impact on JIT systems, and which are pertinent to the proceeding arguments of the thesis;

BOTTOM-UP MANAGEMENT

Krajewski et al, wrote:

> "Bottom-up management, is at the base of Japan's productivity achievement. Decisions are made by committee and consensus at lower levels rather than by top-down edict as in the U.S. Operating decisions are made at the lower levels of the organisation, thereby involving the foremen and workers who must implement the decisions.".

This bottom-up approach to production planning places the shopfloor in charge of local decision making, thus introducing a high degree of involvement in the management of the plants operations. The MRP methodology, however, does not involve the shop floor in the decision making processes, by imposing suggested start and end dates for work orders.

+/- ZERO PERFORMANCE TO SCHEDULE

Zero performance to schedule, refers to finishing the daily production schedule each day, even if it takes overtime to do it.

DESIGN OF BALANCED FLOW

Streamlining of the process flow, is achieved through effective physical layout design, by employing Group Technology principles (see section 5.3). The ratio between value-added time to non productive queuing time is maximised, through the elimination, as far as possible ,of in process buffers and conveyors.

FOCUSED FACTORY DESIGN

Skinner (1974), first mooted the concept, that to eliminate conflicts between production needs of different products, the production system should be specifically designed for a limited number of product lines, Finch et al (1986).

CONSTANT REDUCTION IN SET-UP TIMES

Single set-up concept, which according to Monden (1983), implies a single digit set-up time of less than 10 minutes, is achieved through:

(1) separate internal set-ups from external set-ups; internal set-ups

being those that cannot be done while the machine is running and external those that can;

(2) Convert internal set-ups to external whenever possible;

(3) Eliminate the adjustment process. Adjustments to machines usually take 50-70% of the total set-up time and minimising adjustment time is therefore

critical;

(4) Abolish the set-up steps. Standardise parts within and across product lines or produce various parts on small, rather than large machines. For the same work centre capacity, flexibility is increased by using a large number of small machines rather than a small number of large machines. Also, by using smaller capacity machines, failure of one piece of equipment has less impact on work flow, Finch et al (1986).

The other objective of reduced set-up time being the achievement of production, utilising a batch quality of only one.

PRODUCT SIMPLIFICATION

Employing yet an other borrowed Group Technology principle, constant rationalisation of product range is achieved through simplification of the production process and utilisation of common parts across the product range.

HIGH MACHINE RELIABILITY

To remove uncertainty from the production process, a programme of preventive maintenance is invariably incorporated into JIT systems, reducing machine down times and waste. Finch et al (1986), wrote:

> "Japanese workers are very knowledgeable of their machine's maintenance needs and could do many repairs themselves. Though they do not actually do these repairs, they understand what needs to be done, and can identify maintenance problems while they are still minor, preventing major problems and breakdowns.".

CELLULAR MANUFACTURING ORGANISATION

Autonomous cells, being totally responsible for their own production planning and procurement from other cells, are a common feature of JIT systems. The self management philosophy, extends to areas of scheduling, maintenance and flexible multi discipline work force. Finch et al, also wrote:

> "Planning and control of parts production are simplified by treating the group of machines as one work centre, thus decreasing the number of work centres and and simplifying the routing of parts.".

The GT approach also advocates the simplification of routings and autonomous organisation and planning of the shopfloor activities, as long as they satisfy the overall production requirements of the factory as a whole.

SMOOTHED PRODUCTION RATE IN LINE WITH MARKET DEMAND RATE

Standardised containers, use of mixed models and smooth production build rates are consistently applied to the function of production process planning. In fact build rates taking a cycle time of a months are common. The element of flexibility in the design of the cells mentioned above, serves to allow concurrent assembly of different models on the same production line. The standard transport containers, also aid in simplifying the management of the overall production plan.

CONTINUOUS IMPROVEMENTS IN QUALITY AND PRODUCTIVITY

Quality and productivity improvements, whilst reducing the work-in-progress levels, are the mainstay of the JIT systems. WIP reduction as a matter of policy, is applied to the production lines to highlight production problems which would have been shielded by the existence of buffers in the system. These problems would then be immediately resolved to maintain production. Dr. Demming's total quality philosophy, Neave (1988), which among other things states:

> "The most important part of the production line is the customer" and " profit in business comes from repeat customers, customers that boast about your products and service, and that bring friends with them.",

has over the last thirty years, become an indispensable element of the Japanese JIT systems. The prevalent quality control concepts in the West, which as Neave, correctly argued, approach quality in terms of:

> "satisfying the customer at the lowest possible cost",

and the BS5750 which views quality in terms of fitness for purpose sense:

> "is the product designed and constructed to satisfy the customers needs?",

hardly touch on the Demming's approach. A decade ago, the customers were satisfied that a Japanese product that they were familiar with, such a television set, was more reliable than an equivalent Western product. However, the customers were not asking for potable video cameras that they could afford or multi function video recorders. It was the industrialists who created the products and convinced the customers that they should be buying the new products. Similarly, the customers were used to 12 month guarantee on products, but it was the Japanese that now routinely offers longer periods of guarantee on their products, including three year guarantees on automobiles. The conclusion therefore, is that it is not enough to think about what the customers are wanting or the level of quality with which they are happy now, rather industrialists should be surpassing expectations in products quality and design to stay ahead of their (mainly Japanese) competitors.

Zero defect in products, is the long established goal of the Japanese industries and statistical process control and work team quality control, are amongst the common elements of this goal.

The similarity of approach with GT principles is again evident. The autonomous cells in the GT environment also deal with specific product groups, the cell operators are therefore knowledgeable about the range of products that they manufacture and are responsible for the quality control of those products. The ability to easily identify a product group with a particular cell, is a strong motivating factor to produce high quality products in each cell.

JUST-IN-TIME PURCHASING AND DELIVERY

The manufacturing materials and components purchased from reliable vendors, in compliance with the delivery schedules of the kanban pull system which as was stated earlier, triggers the movement of material from one operation to an other, and to the quality standards above, through cooperation between the vendors and the purchasing organisation.

Purchased parts, just as manufactured parts, should be delivered to the assembly area just in time for assembly into the finished products.

Half the vendor industries operating in Tokyo, had by 1978, adopted the kanban system, Clutterbuck (1978).

4.2.3 REVIEW OF JIT/KANBAN SYSTEMS

The number of JIT system implementations in the Western countries, in particular the U.S.A., have been increasing since the late 1970s, Schroer et al (1985), Swan (1986). Successful companies have reported dramatic improvements in their performance and the unsuccessful companies tend to blame their vendors. The JIT/Kanban user in Japan tend to have the following characteristics:
(1) they are mainly implemented in a repetitive manufacturing environment where it would be possible to freeze the schedule for a fixed period of time;
(2) the location of vendors tend be near the assembly plant;
(3) the product mix also tends to be limited to reduce potential disruptions to the production line.

The the credibility of the JIT philosophy, in the eyes of the Western industrialists, has grown in the 1980s due to the ability of the

Japanese export oriented industries, to maintain and increase their market share, even with the Yen's threefold increase, against the value of the U.S.Dollar, over the last decade. Clearly the Japanese have concentrated on the those elements of the JIT system's approach, which would allow them to increase productivity whilst maintaining their product quality. It is suggested that their Macro economic philosophy, which plans for long term growth, has allowed the organisations to accept reduced profit and in certain cases, losses in the short term (in adverse economic conditions) whilst they carry out their programme of productivity improvements to maintain their export lead economic growth. Dreyfuss (1986), in an editorial in the FORTUNE journal wrote:

> "With the yen up 36% in a year against the dollar, Japanese companies are slashing costs, squeezing suppliers, and-as long as they can stand it-taking losses to hold markets. They are even buying finished goods from low-price producers like the U.S...... The new reality of *endaka* (the high yen) has Japanese companies scrambling to shape and manage more complex business strategies.".

With the advent of Japanese investment in plants situated in the Western countries, their style of management is also being exported. It is argued that it is in their interest if their philosophy of management takes route in the western industrial culture. Those vendors wishing to partake in this phenomenon, have embraced the JIT techniques in the knowledge that they are more likely to survive in the future decades, if they follow the Japanese.

4.3 THE OPTIMISED PRODUCTION TECHNOLOGY (OPT) PHILOSOPHY

The history of the development of OPT philosophy, along with most of the information about how computer software, works has been skillfully handed out by a successful team of entrepreneurs headed by Dr. E. Goldratt. Legend has it that the two Goldratt brothers one a physicist and the other a computer scientist, attempted to use a computer for production scheduling. Fox (1982), of Creative Output inc.(suppliers of the OPT software) wrote:

> "Their biggest asset was not their computer and mathematical abilities, but an innocence of what we professionals know about scheduling......In 1979 they brought the OPT system to the United States and established a U.S. company-Creative Output Inc..... they developed a computer system that is not based on traditional approaches....I believe it is the real answer to Japanese competition and an approach that needs to be quickly and widely embraced throughout U.S. industry.".

Their innocence has been matched with a series of detailed analyses of what is wrong about MRP II and JIT techniques, which are surprisingly well researched. It is suggested that the OPT philosophy is a hybrid of previous developments in the field of production planning and control, and that it relies to a large extend on the basic elements of JIT philosophy, the findings of Group Technology researchers and MRP II system developments. The significant feature of OPT philosophy which is unique, is the business orientation of it's message and the recognition of the important role of bottlenecks in manufacturing plants. The basic philosophy and it's rules will be discussed next.

The OPT philosophy could be described as a product of the hybrid thinking. It is a logical approach to production scheduling and total manufacturing management. OPT philosophy deduces a set of commandments based on the following supposition:

> "There is one and only one goal for a manufacturing company-TO MAKE MONEY. All other activities such as quality control, the skills of work force, the type of technology and the like, are means to the goal, but are not the goal of manufacturing.", Goldratt et al (1984).

NET PROFIT (NP), an absolute measure of how much money was made;

RETURN ON INVESTMENT (ROI), a relative measure of how much money was made in relationship to the money invested;

CASH FLOW (CF), the red line of survival;

THROUGHPUT (T), the rate at which money is generated by selling the products we produce;

INVENTORY (I), the money invested in purchasing things which the system intends to resell, but not sold yet;

OPERATING EXPENSE (OE), the money we spend in order to turn inventory into throughput. Fox (1983a), wrote:

> "The goal of manufacturing becomes to simultaneously increase throughput, while decreasing inventory and operating expense.".

To achieve this objective, there are eight broadly termed 'scheduling' and two 'cost accounting' commandments, which for optimal results need to be applied simultaneously, hence the advantage in utilising the OPT software. The commandments could also be applied in any organisation without the software, given, extensive reeducation of the top and middle management. Figures (4.6 to 4.8) are a comparison of conventional and OPT rules of running an organisation. The principle difference between the traditional approach to scheduling, and that of OPT is that MRP II methodology tries to balance capacity (utilising the CRP module), ie, each productive resource is scheduled to operate as far as possible to it's available capacity. The importance of smoothing the unevenness in the work load is emphasised. But OPT, similar to

CONVENTIONAL RULES V **O P T COMMANDMENTS**

1- BALANCE CAPACITY, THEN TRY TO MAINTAIN FLOW.

BALANCE FLOW NOT CAPACITY.

2- LEVEL OF UTILISATION OF ANY RESOURCE IS DETERMINED BY ITS OWN POTENTIAL.

THE LEVEL OF UTILISATION OF A NON-BOTTLENECK IS NOT DETERMINED BY ITS OWN POTENTIAL BUT SOME OTHER CONSTRAINT IN THE SYSTEM

3- UTILISATION AND ACTIVATION OF WORKERS ARE THE SAME.

UTILISATION AND ACTIVATION OF A RESOURCE ARE NOT SYNONYMOUS.

4- AN HOUR LOST AT A BOTTLENECK IS JUST AN HOUR LOST AT THAT RESOURCE.

AN HOUR LOST AT A BOTTLENECK IS AN HOUR LOST FOR THE WHOLE SYSTEM.

5- AN HOUR SAVED AT A NON-BOTTLENECK IS AN HOUR SAVED AT THAT RESOURCE.

AN HOUR SAVED AT A NON-BOTTLENECK IS A MIRAGE.

Figure (4.6) AFTER FOX (1983a)

CONVENTIONAL RULES V **O P T COMMANDMENTS**

6- BOTTLENECKS TEMPORARILY LIMIT THROUGHPUT BUT HAVE LITTLE IMPACT ON INVENTORIES.

BOTTLENECKS GOVERN BOTH THROUGHPUT AND INVENTORIES.

7- SPLITTING AND OVERLAPPING OF BATCHES SHOULD BE DISCOURAGED.

THE TRANSFER BATCH MAY NOT, AND MANY TIMES SHOULD NOT, BE EQUAL TO THE PROCESS BATCH.

8- THE PROCESS BATCH SHOULD BE CONSTANT BOTH IN TIME AND ALONG ITS ROUTE.

THE PROCESS BATCH SHOULD BE VARIABLE NOT FIXED.

9- SCHEDULES SHOULD BE DETERMINED BY SEQUENTIALLY;

* PREDETERMINING THE BATCH SIZE

* CALCULATING LEAD TIME

* ASSIGNING PRIORITIES, SETTING SCHEDULES ACCORDING TO LEAD TIME

* ADJUSTING THE SCHEDULES ACCORDING TO APPARENT CAPACITY-CONSTRAINTS BY REPEATING THE ABOVE THREE STEPS.

Figure (4.7) AFTER FOX (1983a)

CONVENTIONAL RULES V O P T COMMANDMENTS

9- SCHEDULES SHOULD BE ESTABLISHED BY LOOKING AT ALL OF THE CONSTRAINTS SIMULTANEOUSLY. LEAD TIMES ARE THE RESULT OF A SCHEDULE AND CANNOT BE PREDETERMINED.

MOTTO;
THE ONLY WAY TO REACH A GLOBAL OPTIMUM IS BY ENSURING LOCAL OPTIMUMS.

THE SUM OF THE LOCAL OPTIMUMS IS NOT EQUAL TO THE GLOBAL OPTIMUM.

Figure (4.8) **AFTER FOX (1983a)**

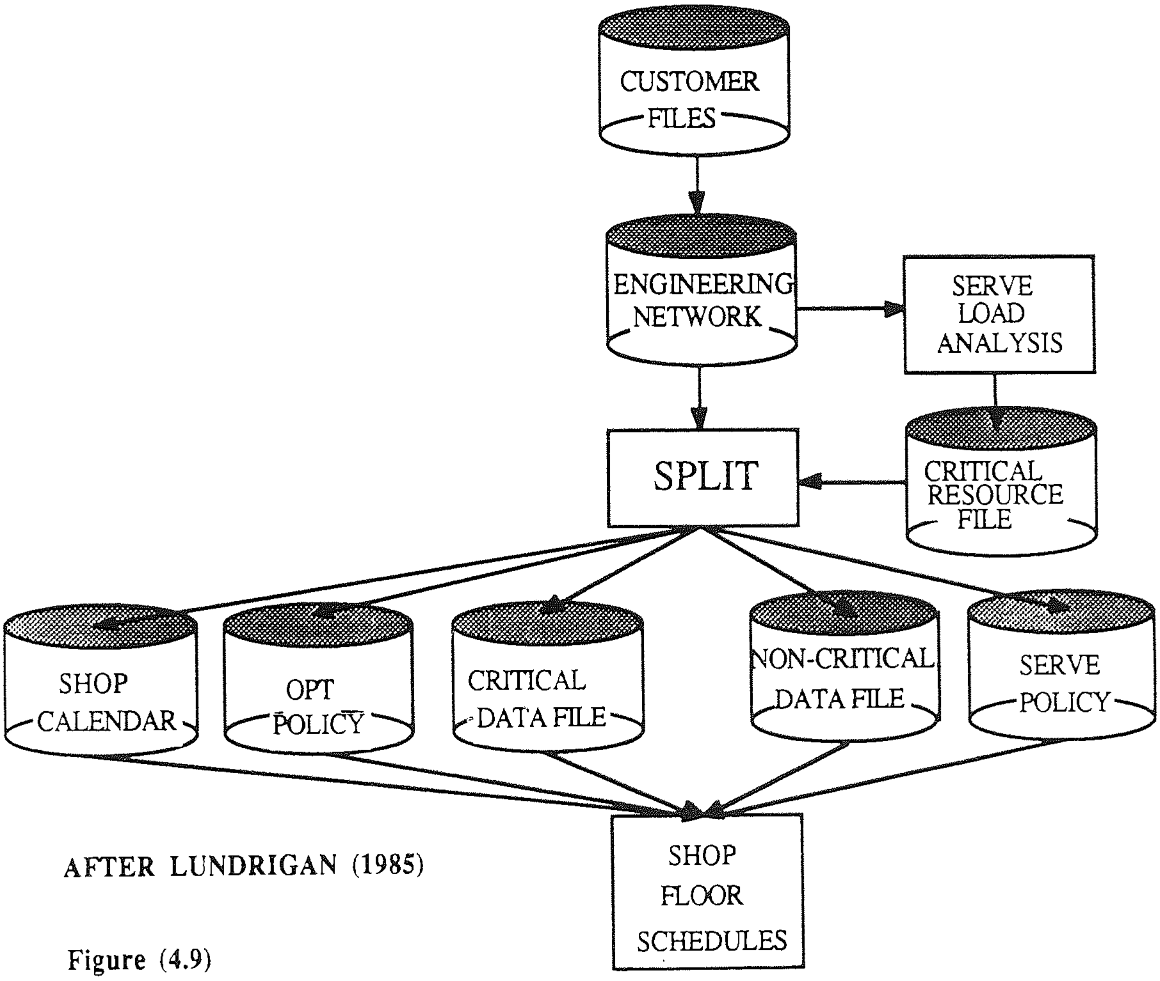
kanban, tries to balance flow, i.e., full utilisation of every productive resources is not attempted. Instead, the schedules are designed to ensure a steady flow of goods through the manufacturing plant, to achieve lower WIP and shorter manufacturing lead times.

Goldratt, argued that any given manufacturing plant should not and can not be balanced. Every plant depends on the 'average' rates to schedule its production , and the deviations from the mean, in any given time, would at times be quite high, thus, the data has a 'non-determinate' character. These variations, coupled with the effects of 'interdependence' (ie, different stages of manufacture from one operation to an other or from a department to an other), cause wave patterns in plants with adverse effects on WIP, throughput, lead times and competitiveness of a plant. If resources are utilised to their maximum capacity, regardless of their effect on actual throughput, the WIP levels will tend to increase. Of course, if each resource is set up to produce large batches in order to increase its local efficiency, other work which needs to be processed by that resource would remain as WIP over a longer period of time, thus increasing the overall WIP levels, and the overall production lead time of the products, when this approach is applied to every resource in the manufacturing plant. The large amount of WIP is valuable capital which is being tied up in the plant which the Japanese Kanban approach tries to avoid.

Here the Goldratt's analogy of balanced plant can be misleading. It can be argued that Kanban attempts to balance resources to very good effect. However, the former refers to balancing the inherent capacity of a resource with a corresponding level of work, but the latter, refers to balancing the resources to maintain constant and smooth flow of work, with the smallest possible transfer batch sizes to reduce WIP.

The number of batches awaiting processing on resources which are set up to process large batches means that the full utilisation of every productive resource, regardless of its relative effect on the production plan, would reduce the overall throughput of the plant. In reality however, the management will temporarily abandon this balanced concept when it gets out of hand, usually near the end of the month when deliveries are promised. By distinguishing between bottleneck and non-bottleneck resources, the OPT rules concentrate on increasing throughput by maintaining maximum utilisation on those resources that yield genuine increases in saleable throughput. Figure (4.9) shows an overview of the OPT system.

AN OVERVIEW OF THE OPT SYSTEM



AFTER LUNDRIGAN (1985)

Figure (4.9)

4.3.1 THE OPT METHODOLOGY

Figure (4.10) shows a typical product explosion from orders to raw materials where two operations have been identified as occurring on bottlenecks.

OPT

PRODUCT EXPLOSION FROM ORDERS TO RAW MATERIALS

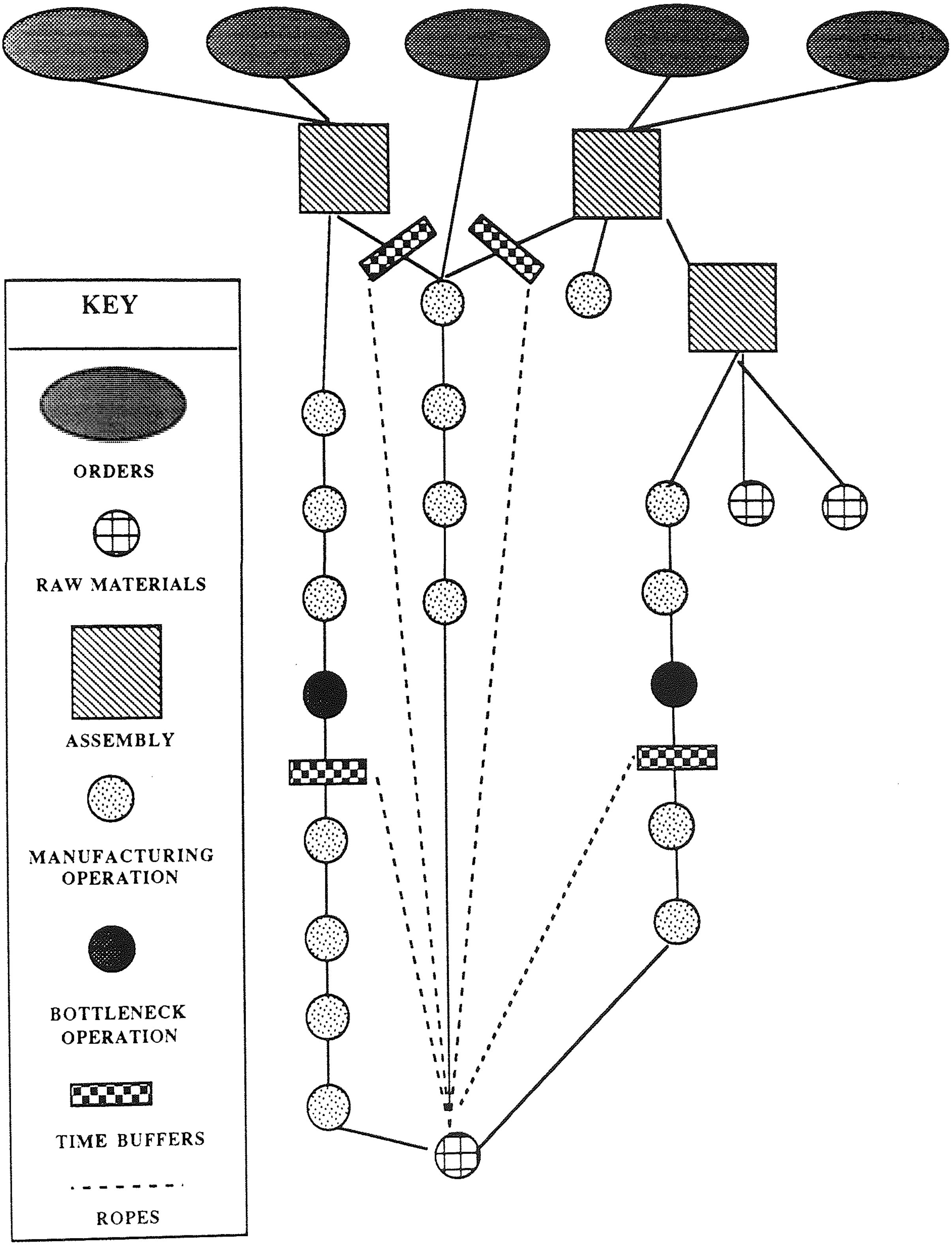


Figure (4.10)

AFTER HARISON (1985)

The OPT software, utilises the production requirements and available manufacturing resources to produce optimised schedules. The methodology differs to that of MRP in the following respects.OPT builds a model of the manufacturing plant which contains the bill of materials and the routing layouts as well as detailed data about the available resources. The system explodes the demand through the model and loads the resources to infinite capacity. The bottlenecks are identified and then verified through limited checks on the accuracy of the relevant data.

To optimise the schedule on the bottlenecks OPT splits the model into two networks, MASTER NETWORK and the SERVE NETWORK, Harrison (1985). The Master network contains the orders and the bottleneck operations and a simplified picture of their inter-relationships, figure (4.11). A bottleneck could be machine, men, jigs, tools, fixtures or supply of materials or components. The OPT algorithm then attempts to schedule the bottleneck operations to as far as possible, meet the market demand. Priority and capacity are considered simultaneously, and the use of bottlenecks is maximised by forward scheduling.

After allowing for the lead time between bottleneck and order, a feasible Master Production Schedule based on achievable dates is produced, figure (4.12 a).

OPT

THE SIMPLIFIED MASTER NETWORK

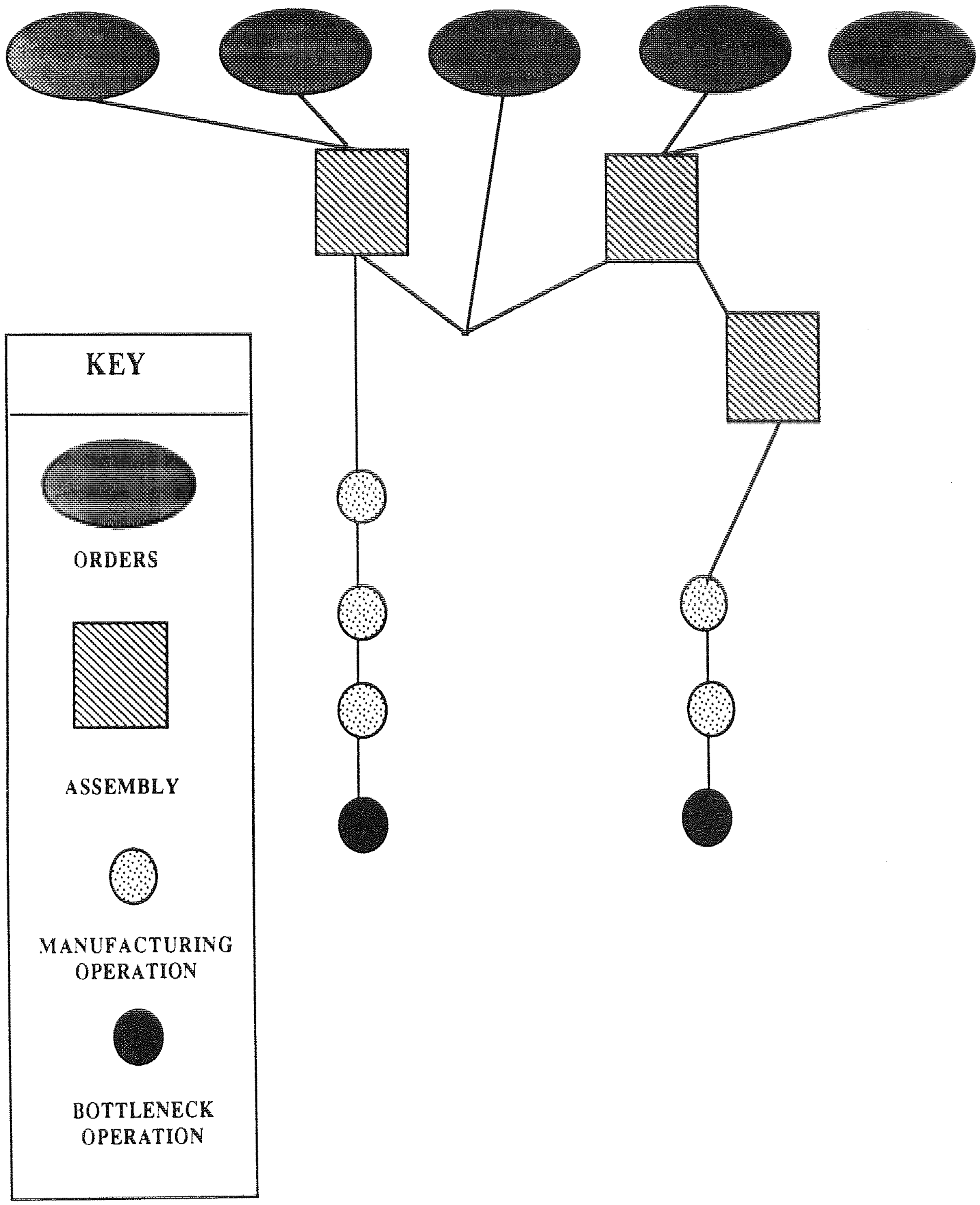


Figure (4.11)

AFTER HARISON (1985)

FORWARD & BACKWARD SCHEDULING OF OPT SOFTWARE

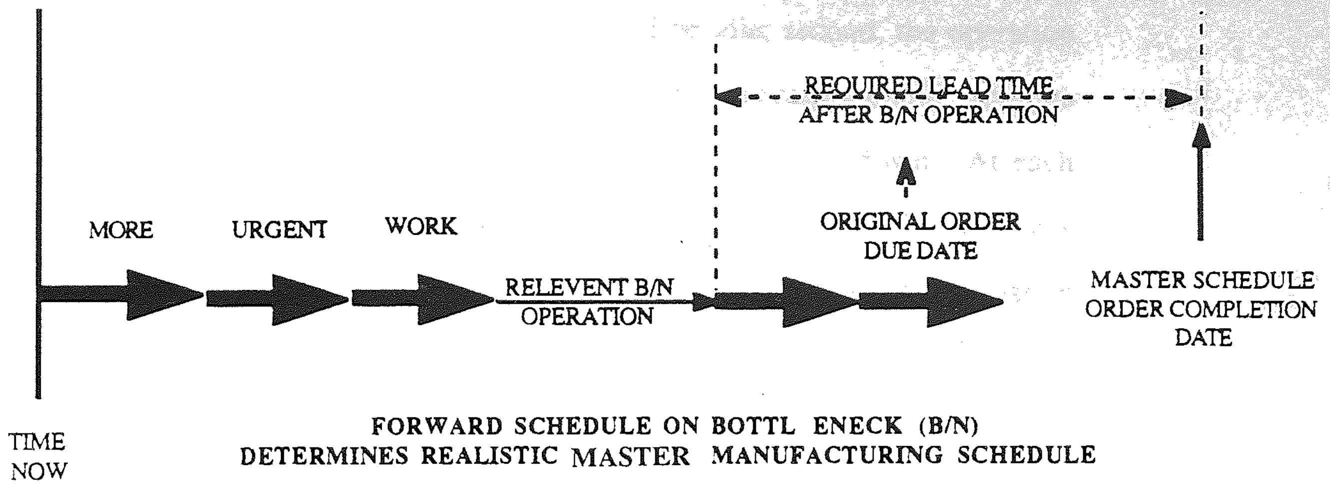


Figure (4.12 a)

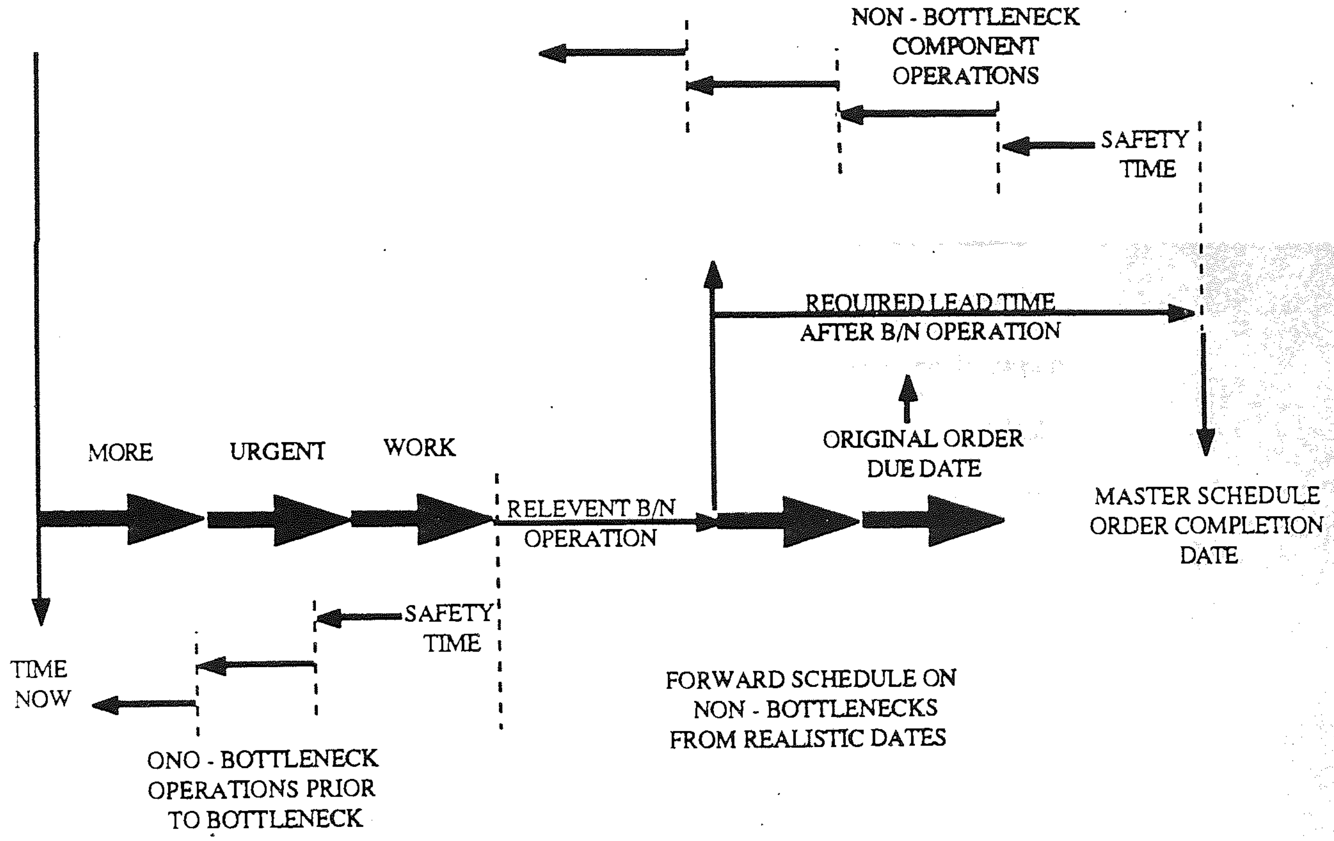


Figure 4.12 b)

AFTER HARISON (1985)

The MPS dates based on the optimised schedule are passed to the SERVE network, where non-bottleneck operations are backward scheduled, figure (4.12b). At each interval in time, a number of things could occur for each of the operations defined for a particular product. First, the operation could be idle; second, the operation could start up from idle state; third, operation could continue processing, or fourth, the operation could shut down. At each interval of time, decisions concerning each operation for each product must be made. To make these decisions, OPT system prioritises the products at each interval of time. The priority that a product obtains is calculated using a weighted function using a number of criteria. Some of the criteria that may be considered include the desired product mix, required due data (critical ratio), desired safety stock levels, and use of bottleneck resources. OPT system them allocates resources to the highest priority products subject to the availability of the resources during the time interval. A schedule for the planning horizon is then sequentially constructed.

Further details of the scheduling logic and the comparisons between MRP and kanban have been presented in the literature, Fox (1982), Fox (1983b), Harrison (1985), Jacobs (1983), Haylet (1986) and Whiteside (1984).

4.3.3 REVIEW OF OPT METHODOLOGY

The schedule optimisation feature of OPT software, based on a proprietary algorithm does not in itself remove the need for an MRP system to carry out the material requirements planning functions in a manufacturing plant. Swan (1986), in a review of the OPT software wrote:

> "Early comparisons discussed MRP and OPT as 'either/or.' A company may in fact need both tools: MRP for net requirements and OPT for realistic shop schedules. Using OPT as a scheduling tool in, for instance, a job shop, does not preclude

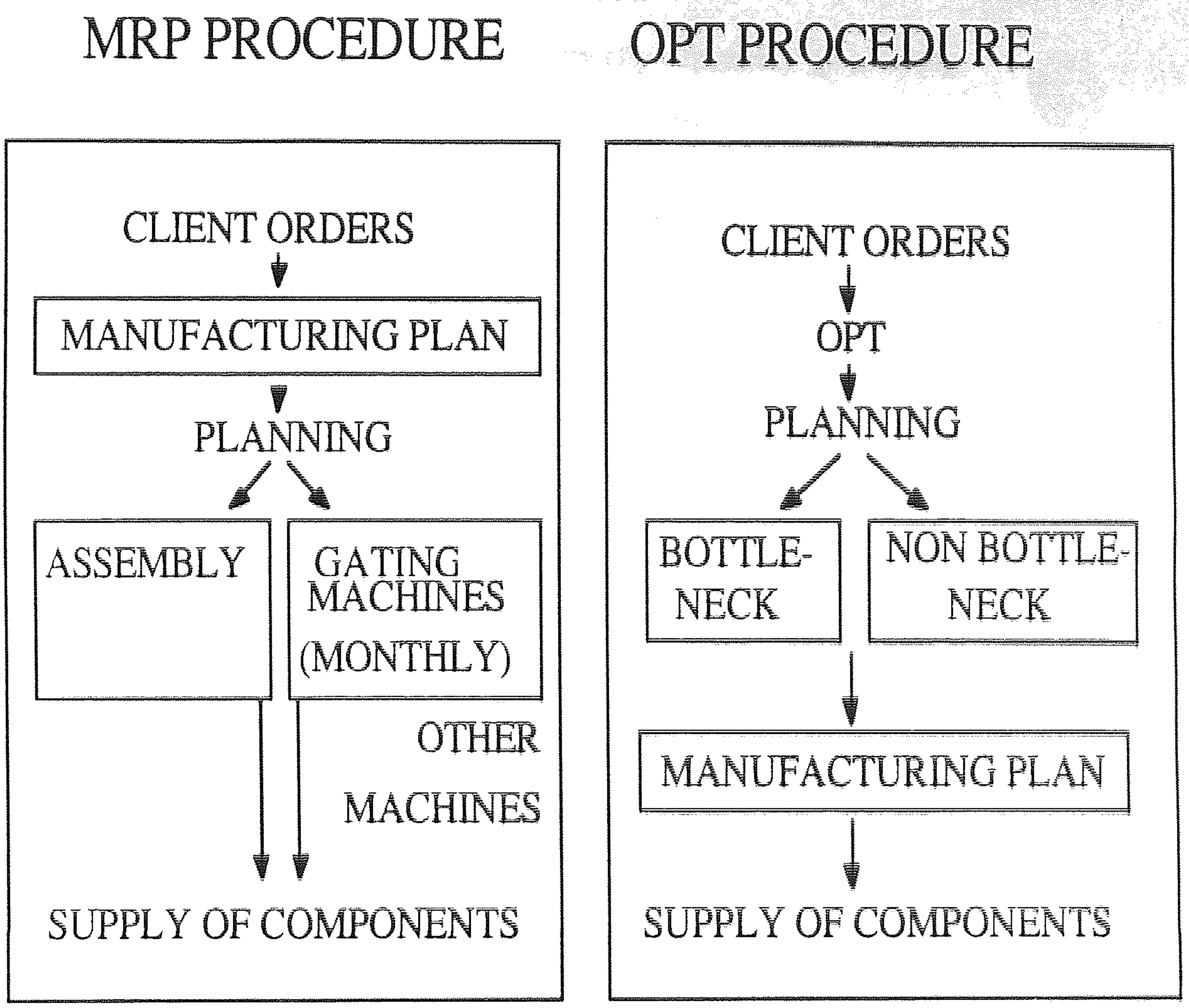
> the need for accurate bills of material and disciplined inventory planning and control. MRP is the appropriate tool to provide bills of material and inventory management features... A heavyweight synchronised scheduling challenge requires OPT. Finally, both MRP and OPT require a solid foundation. OPT is not 'easy MRP' and is no more likely than MRP to produce good outputs from bad inputs.".

The finite scheduling of only the bottleneck operations, to 100 % capacity, reduced the the need to smooth away the overloads on non bottleneck operations, since they would have much more spare capacity. The realisation that uniform high utilisation of all the resources to their maximum capacity would lead to increased WIP and long lead times, however, had long been recognised by Burbidge (1971), Burbidge (1983), Dudley (1970), Hollier et al (1966), OPT has incorporated this knowledge into it's methodology.

The evaluation of plant behaviour , post implementation phase, was in the early days, positively discouraged and to date the author is unaware of comprehensive research relating to the performance of the software or the plant performance after the initial benefits have been realised. However, Jacobs (1983), in a review of the OPT software based on a test benchmark observed that:

> "It does not appear that the program considers the size of WIP in any way other than to ensure that minimum safety stock levels are maintained. In the test problems, values for WIP on the order of 20 times higher than could have been obtained for the desired production rate were observed......It would appear that OPT would work best in a high volume, large batch-size operation with few individual production operations. Here the problems with carrying high work-in-process inventory are minimised due to the few operations involved and the high production rates.".

Figure (4.13), indicates the centralised nature of both MRP and OPT systems. It can be argued that the centralised (and global) nature of the system removes much of the key decision-making from



- * MONTHLY PLANNING OF GATING MACHINES
- * WEEKLY ADJUSTMENTS ACCORDING TO IMPORTANT EVENTS

- * WEEKLY PLAN
- * DETAILED BOTTLENECK SCHEDULE
- * SYNCHRONISED NON BOTTLENECK SCHEDULE

WITH OPT THE PLAN IS MADE ACCORDING TO THE CONSTRAINTS AND IS NOT PREDETERMINED

Figure (4.13)

the shopfloor but is nevertheless critically dependent upon timely and accurate feedback of shop performance data.

System performance rests upon good communications between the shopfloor, where knowledge of the plant status and capacity is greatest, and the OPT analysts. The temptation to set the plant parameters once and simply follow the schedule must be high. This would result in one off improvements in plant performance over a period of time.

In all centralised systems it is difficult to implement the concept of ownership. A manger who 'owns' a system is more likely to be committed to its successful operation. In general it is necessary for the system to operate largely within the span of control of the manager concerned. The size and scope of most large manufacturing control systems forces the level of 'ownership' well above the people responsible for day-to-day operation of the plant.

OPT , however, in common with the Japanese JIT techniques, recognises the importance of low inventory and high saleable throughput. It attempts to balance the flow of materials utilising a computer; which allows the introduction of synchronised manufacturing to industries where Kanban techniques would not be appropriate.

4.4 CONCLUDING REMARKS

It is suggested that the development of the computerised MRP and MRP II systems, has transformed the manufacturing planning and control functions from a 'seat of the pants' art into a methodology driven art. With the advent of Material Requirements Planning systems the inventory planning made use of dependent/independent demand principle reducing the dependence on past data. The production planning function was formalised through the advent of MRP II systems, with rough cut capacity planning and capacity requirements planning. The use of average lead times based on past performance and capacity insensitiveness are the major limiting factors inherent in all MRP systems. Orlicky (1975), in his introduction to MRP systems wrote:

> "A material requirements planning system is capacity-insensitive in that it will call for the production of items for which capacity may not, in fact, exist. This might appear to be a shortcoming of material requirements planning but, on a moment's reflection, it can be seen that this is not so. A system can be designed to answer either the question of what can be produced with a given capacity (i.e., what the master production schedule should be) or the question of what need be produced (i.e., what capacity is required) to meet a given master production schedule, but not both. An MRP system is designed to answer the latter question.".

A typical production manager, however, is more likely to want the answer to 'what should be done next?' or 'what options are available?. It could be argued that if the above quotation had been written on all the MRP II system manual sold over the last two decades, the number of organisations which have not been successful in implementing these systems, might have been less. The current centralised data structure and computer processing configuration of the conventional MRP/MRP II systems as well as the OPT system, are technological constraints which the 1960's technology imposed on development of computerised production planning and control systems.

Furthermore, the Japanese experience shows that the involvement of the shop floor personnel in the daily operations of a manufacturing plant makes a great deal of commercial sense. It is therefore suggested that in the light of the difficulties in successfully implementing MRP II systems, a more practical production planning and control approach should be developed. This approach could utilise a large pool of practical knowledge which is available. These range from the JIT techniques and the OPT philosophy to the GT principles. The existence of new data processing technologies is a further compelling reason to attempt to develop a more practical approach to production planning and control. The development of such an approach would necessarily include a process of hybridisation which would attempt to encapsulate the best features of the current 'state of knowledge' in the field of production planning and control. The discussion in the following chapter will explore the characteristics of current hybrid systems.

CHAPTER 5 HYBRID PRODUCTION PLANNING AND CONTROL SYSTEMS

This chapter will discuss some of the hybrid systems which have been developed over the last decade. The term 'MRP system' in some cases refers to MRP II (manufacturing resources planning). The author is aware that in some of the literature the term MRP is used to describe an MRP II system.

5.1 BACKGROUND TO HYBRID SYSTEMS

Whilst the MRP II evolution, as a company-wide approach to manufacturing management has been continuing, a series of hybrid systems incorporating the MRP II and the Japanese JIT techniques have also been developed and implemented. It has taken a long time for the practitioners to accept that the two are not mutually exclusive. The application of JIT techniques such as Kanban in an MRP II environment, clearly has many attractions which will be discussed further. The literature suggests that there is still a tendency to espouse the virtues of one approach against the other, Goddard (1982), Fox (1982).

It is argued that the designer of production and inventory control systems, has to deal with basically the same inherent characteristics of the control elements, in a factory situated in Tokyo or in Birmingham. Also, the processes of production are generally defined and categorised, and various engineering disciplines have through the years successfully exchanged, combined, and developed knowledge to find improved solutions in their respective fields, without much regard for the origin of innovations, with excellent results. In the production and inventory control field however, for many years, most systems designers and systems implementors, appeared to have turned social scientists, without any qualifications. The words 'cultural differences' appeared all over the journals as an excuse for not understanding the basic nature of the problems.

With the advent of Japanese corporations establishing production facilities in the U S A and Europe, utilising local labour, and their ability to produce to the same standards of quality and profitability, attitudes took a turn for the better. White et al (1983), of the Policy Studies Institute, in a detailed study of the experience of British workers under Japanese management concluded that:

> "In accepting working practices which involve a high degree of commitment and discipline, workers are also in a sense accepting the managerial authority which designs and implements those working practices. The significance of this acceptance of authority is particularly great in the case of the manufacturing companies, since it is between blue-collar workers and management that antagonisms are most entrenched in British society. Against this background, the success of Japanese manufacturing firms in gaining acceptance and support for their methods of management has been remarkable..... What impressed workers was not the patronising graces of egalitarianism, but the fact that management evidently shared the same objectives, tasks and discipline as them...... Their behaviour in becoming deeply involved at the point of production is not a leadership ploy, but part of their technical solution to the problem of achieving high and consistent levels of efficiency.....This does not mean that British firms should copy Japanese systems in their entirety (even if it was possible). Rather, it means that they must analyse and evaluate their own systems as a whole, and then perhaps adapt details of the Japanese approach wherever these contribute towards an overall advantage.".

Clearly, the achievement of high levels of productivity is possible in the western industrial culture. The involvement of the shop floor work force in the management of manufacturing related operations is a key feature of the successful manufacturing organisations.

However, the relative scarcity of such organisations in the Western industrialised countries suggests managerial resistance to shop floor involvement in the decision making processes. Judging by the success of the Japanese companies in operating manufacturing plants in the U.S.A. and Europe, the old myths about workers not being interested and the burden of management have been quashed. It seems Western managers can justify spending large sums of money in computerised technology under the banner of 'flexibility', whilst resisting any change that brings down traditional management/worker barriers. Integration in manufacturing, it is suggested, should not mean connecting computers together. Rather, it should imply a concerted attempt to utilise the potentially flexible human qualities of the shop floor work force (when appropriate, through the use of available computer technology). Over the last decade here have been a number of attempts to produce hybrid production planning and control systems which will be discussed next.

5.2 HYBRID SYSTEMS INCORPORATING ELEMENTS OF MRP II & JIT/KANBAN

It should be noted that the categorisations of hybrid systems in this section are necessarily loose since in any one system a great deal of concepts and techniques are utilised. The basic cellular principle of JIT/KANBAN systems for example, it could be argued, is itself an element of a hybrid system incorporating GT principles. The following categories however, serve to highlight a progressive change in the general trends in the Western industrialised countries which is in line with the basic philosophy of the thesis.

Belt (1985), of the Oliver Wight Education Associates, in a BPICS conference paper wrote:

> "In 1984, about twenty members of Association Francaise de Gestion Industrielle (AFGI), the French-type professional society, organised a special interest group called MRP/KANBAN, or the creation of zero waste environment. This group serves as a platform for discussion and exchange of experiences of companies implementing Japanese techniques, often to complement or compete with MRP type systems.".

The interesting difference between AFGI group and other similar organisations lies in the fact that they accept that JIT and MRP II philosophies are striving for the same noble objectives, but have obvious central differences in application, which should be explored and understood to pave the way for future systems development. Both MRP II and Kanban systems enable people to work more effectively. The central difference, as Belt argued, lies in the fact that:

> "MRP accepts whatever are the current values of planning parameters such as lead times and lot size. It will immediately generate consistent priority and capacity planning information, whatever the planning parameters are. However, Kanban's primary concern is improving these planning parameters. Kanban wants to shorten lead times and decrease lot sizes in order to simplify priority and capacity planning."

He also pointed out a persistent misconception on the part of industrialists when it comes to system integration when they become obsessed with the data processing hardware and software:

> "They forget that MRP software, does absolutely nothing but add, subtract and print. The rest is up to the people.... some of the most successful class A companies have some of the most naked software around.".

The paper also presented three examples of successful hybrid Kanban and MRP II systems. Parnaby (1988), the Director of Manufacturing for Lucas Industries in the UK, wrote:

> "A survey of best international practices showed that in general Japanese companies had the most competitive overall

> performance and Western companies in Europe and USA suffered from a triple handicap:
>
> - Many current Manufacturing Systems were originally designed using 1950's methodology for high volume, low variety, medium quality markets and have been modified piecemeal and incrementally with the injection of panacea technologies, to meet evolving competition and market changes. The result is almost unmanageable over-complexity and fragmentation and an inability to perform consistently against the world's best.
>
> - Adequately strong and professional manufacturing development functions, with the knowledge base of Japanese competitors, have not generally been in place in Britain to design and develop the new types of manufacturing systems required to match the best world competition of the 1980's and 90's...
>
> - Manufacturing has been allowed by bad management to become an out-of-date steady-state technician culture as distinct from a graduate-led professional culture in the other functions. This has led to a lack of understanding of the requirements for a competitive manufacturing strategy.".

The major advance in the Lucas approach to systems design lay in the fundamentally clear philosophy of the management. Their success relied on the fact that they rationally asked; what are the best competitors actually doing in their company-wide practices which leads to their market advantage over the indigenous UK industries ?. Armed with facts and not myths, they set about developing an integrated manufacturing philosophy which simplified the overall management of their manufacturing operations by incorporating appropriate production techniques where and when it was necessary without undue emphasis on any one approach. Starting with basic comparative performance data, Table (5.1), and further factual analysis of the Japanese industrial practices, he demonstrated to their managers the factual performance of the Japanese industries.

He wrote:

> "- Cultural differences - but not all Japanese organisations are world leaders in productivity
>
> - Japanese companies use more automation and advanced technology equipment - visits show that many Japanese companies use very similar equipment to that used by British companies and and often achieve much better performance with

older simpler equipment. The skill is to achieve a high capital turnover by mixing simple but modified machines with selectively chosen CNC machines.

- Japanese wage rates are very low - however, the percentage of product cost due to direct labour is often 15% or less. Also many studies have shown that Japanese wage costs are 2-3 times British - our problems result primarily from amateur unprofessional management.".

TYPICAL PERFORMANCE COMPARATORS IN ELECTROMECHANICAL ENGINEERING COMPONENT MANUFACTURE

PERFORMANCE COMPARATOR	JAPAN	WESTERN
SALES PER EMPLOYEE PER ANNUM	£ 125K	£ 50K
STOCK TURNOVER RATIO	15	5
RATIO OVERHEAD STAFF TO DIRECT LABOUR	0.5	1.5
PRODUCT COST	70%	100%
PROPORTION OF ENGINEERS IN OVERHEAD STAFF	60%	20%
RATIO $\frac{\text{ENGS IN PRODUCT DEVELOPMENT}}{\text{ENGS IN MANUFACTURING DEVELOPMENT}}$	1.1	10
LEAD TIMES IN DEVELOPMENT & MANUFACTURE	50%	100%

KEY ENGS => ENGINEERS

Table (5.1) **AFTER PARNABY (1988)**

This fundamental review led to the introduction of a multidisciplinary development job of Manufacturing Systems Engineer which was supported by an in-house developed programme of training designed to nurture a Total Quality Programme to develop total quality of performance in all functions.

Figure (5.1) is a diagrammatical representation of their strategy-lead total systems engineering approach to achieve their goals.

INNOVATION FOR IMPROVING MANUFACTURING SYSTEMS

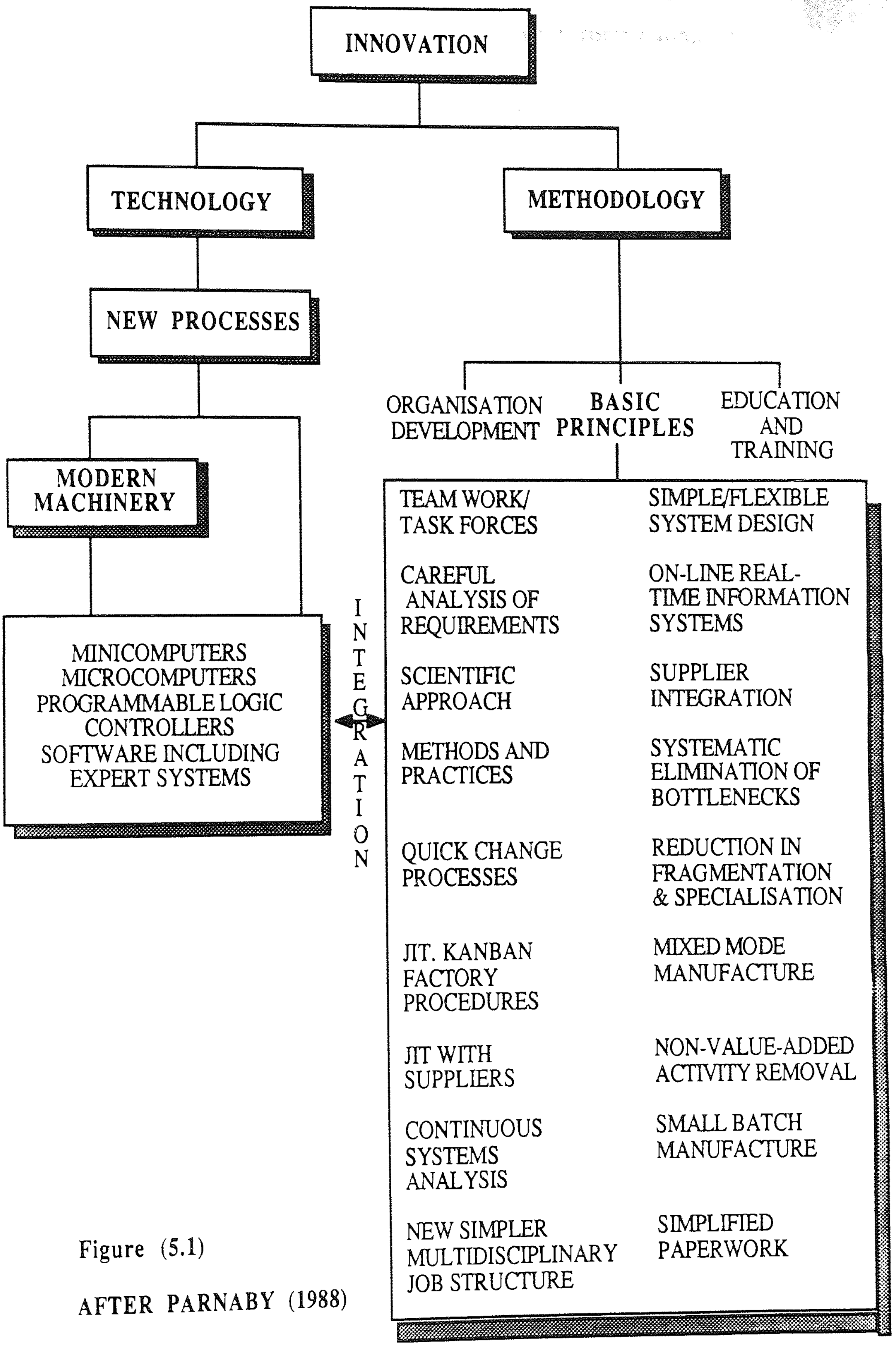


Figure (5.1)

AFTER PARNABY (1988)

Using a Japanese style blend of methodology and technology, with new methodologies being the major element contributing to improved performance through in built simplicity in structure, systems and procedures. The approach included the adoption of a simple business architecture with the business unit divided into product units which in turn were divided into cells, both manufacturing and service. In manufacturing cells, resources were grouped around common material flows and common technologies, utilising rank order clustering and process flow analysis techniques. The administrative cells people were grouped around common information flows, to ensure parallel grouping for short lead time operations. Emphasis on achieving improved effectiveness of total system without preoccupation with piecemeal efficiency and local optimisation.

The approach to selection and design of the most appropriate manufacturing control system is in harmony with the basic philosophy of the thesis. He outlined the limitations of the existing MRP II implementations as:

> "Many MRP II systems, the Western Panacea, have failed to meet their promise or even to be completed. Basic reasons for this problem are:
>
> 1 The imposition of an uniform and over complex computer system on an over- complex manufacturing system...The job is too big, the database too large, there is no ownership and everything is run by committees.
>
> 2 A failure to recognise that different parts of the manufacturing process require different types of control system and different dynamics. Also that a general purpose top-down operations planning systems has to be underpinned by distribution, product and process specific bottom-up execution sub systems designed by Engineers.".

Figure (5.2), highlights the major ingredients of their manufacturing systems design approach which included group technology elements.

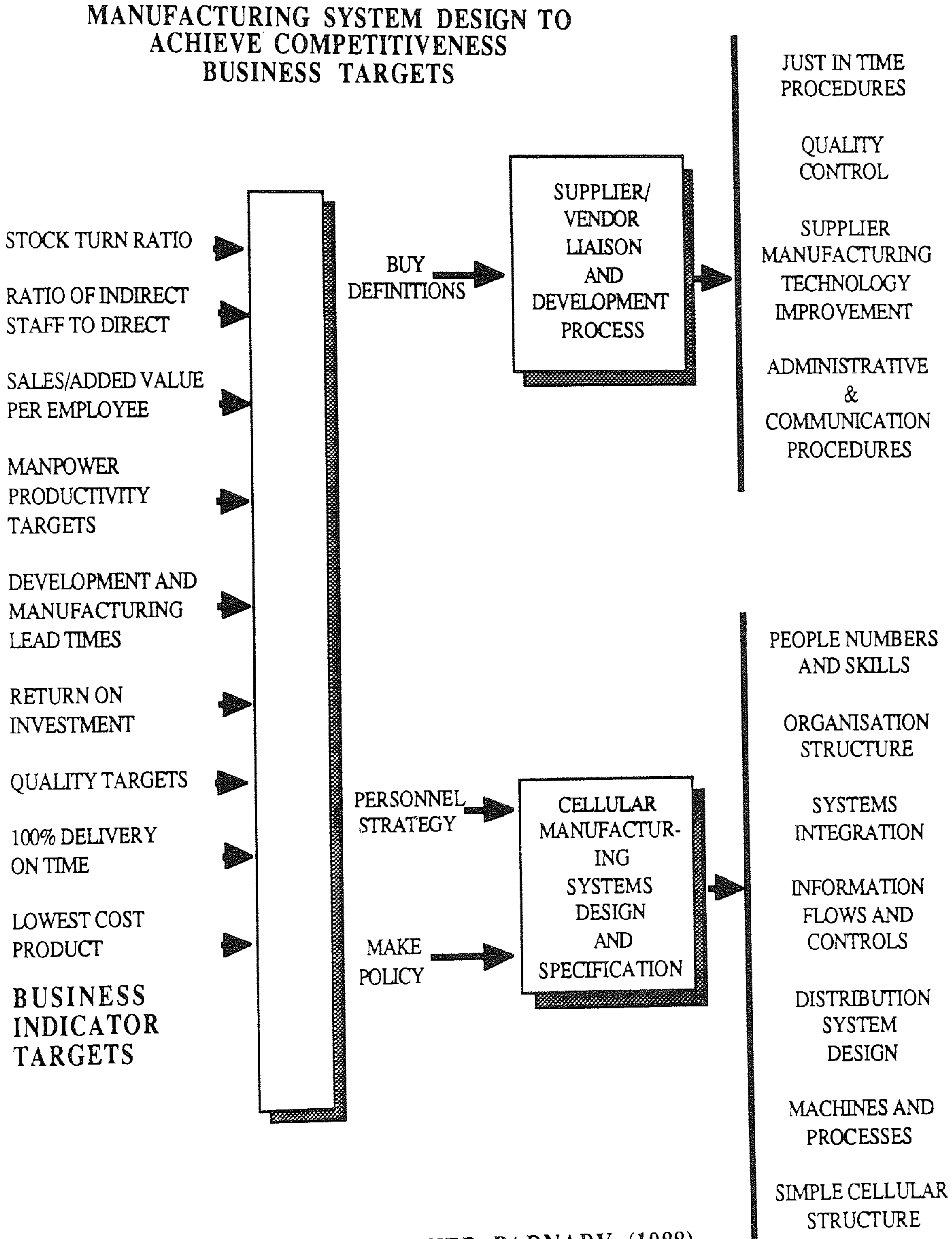


Figure (5.2) AFTER PARNABY (1988)

The realisation that systems at their operational level need to be user oriented and preferably developed by the shopfloor managers is a further positive element of his pioneering style:

> "The Lucas's approach is to use in-house designs of composite control systems;
>
> 1 So that each cell and production unit has the system it needs with simpler dedicated Product Unit Database, not complex total business units database, clearly defined organisational procedures for operation and *clear ownership by the Product Unit Leader.*
>
> 2 There are simple, reliable bottom-up systems in each cell to support the product unit top-down planning system.
>
> Wherever possible, JIT Kanban processes are used to achieve sell-daily make-daily synchronised materials flow for regular *runners to* simplify the control requirement which then is only MRP I, ie raw material procurement to match finished product output schedules... The bonus is much reduced lead times and the achievement of very small batch sizes in mixed mode manufacture which dramatically increases flexibility and *simplifies the control problem....* there is no need to monitor WIP and synchronisation automatically compensates for lead time changes with product mix and work load. Bottlenecks are very obvious, self adjusting and do not need complex simulation and scheduling computer algorithms for control . We have found Kanban to be very flexible and simple to operate in practice.".

(This simple approach to production planning and control however, is in contrast to the computerised OPT scheduling approach which was adopted by Lucas CAV the fuel injection manufacturing subsidiary of Lucas Plc.).

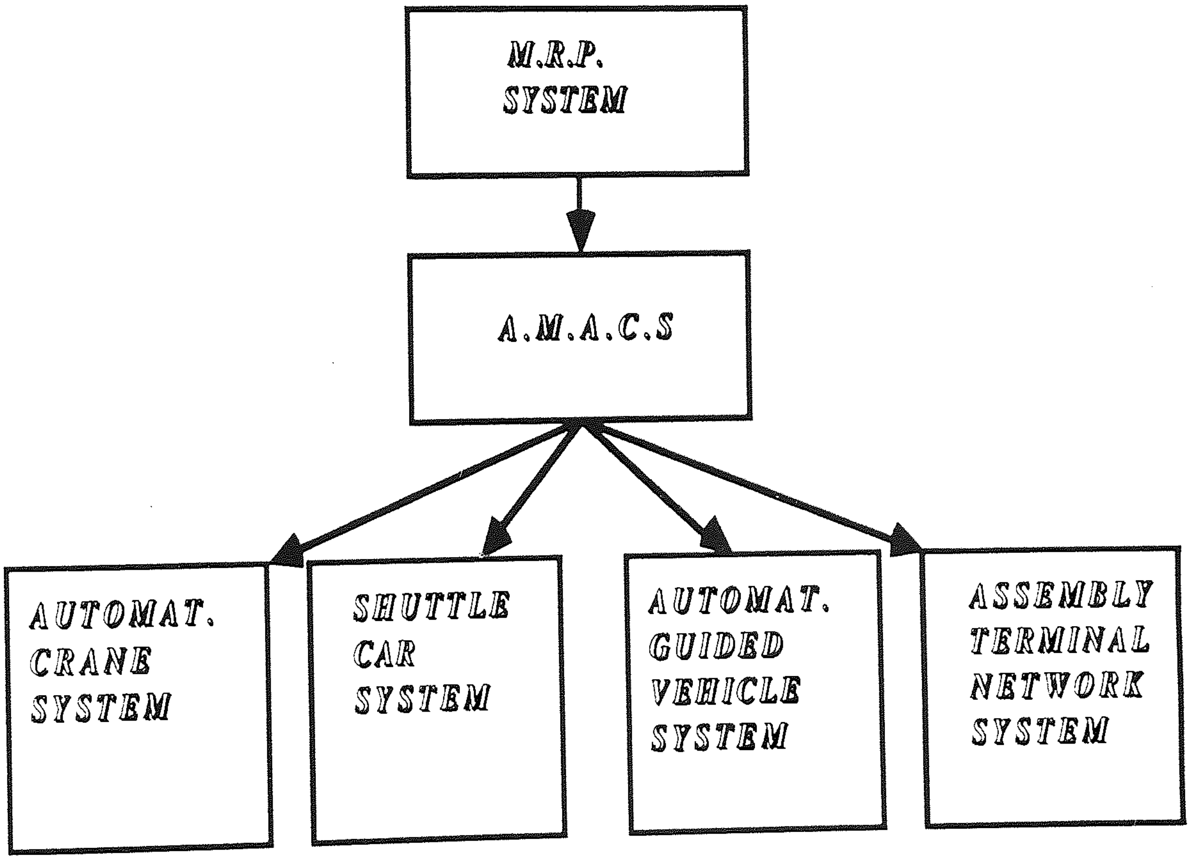
Similarly, Timmer (1985), described how some of the principles of JIT were incorporated in a hybrid MRP II/JIT system in the fundamental changes which were made in the Xerox reprographic business group. He wrote:

> "The cost gap showed that the Japanese were selling their small machines for what it costs Xerox to make similar machines. Since the purchased material is about 80 % of total manufacturing cost and the quality of materials was also a problem, the suppliers were and still are heavily involved in the upgrade programme. After a considerable

> consolidation of the supplier base, long term contracts with single sourcing were introduced, together with statistical process control and Total Quality Control.".

Figures (5.3 to 5.4), demonstrate the features of the Xerox hybrid system which utilises a centralised MRP II system in conjunction with an in-house developed Automated Material Control System (AMACS), to translate the material requirements planning, push replenishment logic into a pull replenishment concept.

MATERIAL LOGISTICS ;
AUTOMATED MATERIAL CONTROL SYSTEM
A.M.A.C.S.

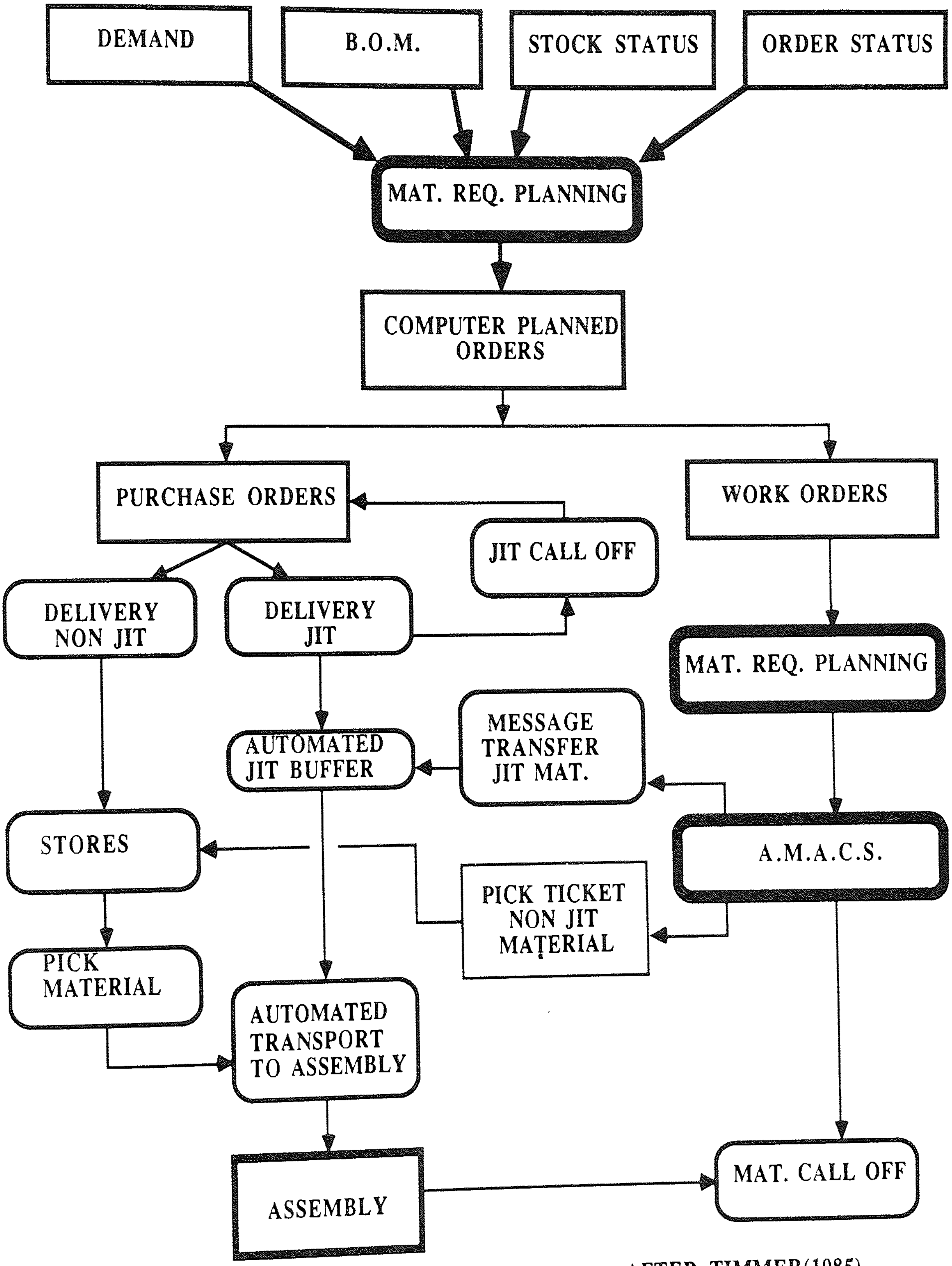


- *COMMUNICATION AND CONTROL SYSTEM*
- *REPLENISHMENT CONTROL SYSTEM THAT TRANSFERS MRP-PUSH-REPLENISHMENT LOGIC INTO A PULL REPLENISHMENT CONCEPT.*

AFTER TIMMER(1985)

Figure(5.3)

MATERIALS MANAGEMENT STRATEGIES;
MATERIAL LOGISTICS / MATERIAL PLANNING



AFTER TIMMER(1985)

Figure(5.4)

5.2.1 CHARACTERISTICS OF HYBRID MRP II & JIT/KANBAN SYSTEMS

Clearly, the dramatic improvements which have resulted when practitioners have undertaken a fundamental review of the state of the art techniques, as was recommended by White et al (1983), and have questioned the prevailing wisdom about what would be a feasible hybrid development and what would not. The integration of JIT philosophy with the computer based MRP II systems whilst yielding exceptionally favourable results, has only recently been adopted in a limited number of pioneering companies.

Parnaby (1988), listed the following benefits from the changes which were implemented:

> "- Business redesigned into three simpler product units and two service units based on process flow analysis and volume/ variety characteristics
> - Average lead times for manufacture reduced from 7 days to 5 hours
> - No-value added activities reduced by 60%
> - Changeovers reduced to a maximum of 5 minutes with increased flexibility
> - U-shaped JIT Kanban cells introduced for 50% of product units to replace traditional linear push systems; piecework removed and productivity (standard hours/direct operator hours) increased by 35%. Personnel reduced by 350. Implementation continuing
> - New organisational structure with fewer layers and flexible jobs
> - Quality circle continuous improvement groups operational
> - Reduced Production Control/progressing staff
> - Stocks reduced by £3.5m (60%). In cell WIP reduced by 90%
> - Batch size of ONE
> - Floor space reduced by 30%
> - Improved product quality.".

Belt (1985), also explained in detail some of the practical advantages of hybrid MRP II/JIT KANBAN systems. It is suggested that none of the above measures are in themselves radical, however, the attempt by a British company to face the Japanese competition by doing what the rest of the industry should have done years ago, is a radical and welcome development. The cell based characteristics of kanban production system, when incorporated in to the MRP II system has lead to the elimination of the intermediate bill of material levels inside these cells. This in turn results in a marked reduction in the number of material requirements planning transactions. In some industrial environments where the hybridisation process has been limited in scope, the need for MRP II systems to have information for products entering and leaving a cell , as well as, the requirement for a Master Production Schedule, has highlighted the fact that the Kanban system in itself would not be applicable to every production item. Belt (1985), wrote:

> "Even Toyota does not use kanban on all its parts, reputedly only 60 % of them.".

The Kanban's prerequisite of a smooth MPS production level may lead to comparatively large holding of finished goods stock. However, the corresponding reductions in WIP levels and improved material flows which lead to removal of uncertainties and plant visibility, are some of the factors which on balance, negate the costs of such a policy. He further pointed out that:

> "Toyota drives its final assembly off customer orders only for the Japanese domestic market. Toyota has learned how to make cars from unmachined foundry pieces to finished automobile in 3 days, less than the customer lead time of 6 days in Japan.... However Toyota still must make sales and capacity forecasts out beyond the 6-day firm order backlog.".

The Kanban system's attributes of planned maintenance, reduced scrap, unidirectional production process, and improved product quality, therefore can be summarised as the unique features which an enhanced hybrid system would add to a MRP II oriented environment. Clearly, the MRP II facility to deal with vendors who are unable or unwilling to adopt a JIT delivery policy, is a major advantage.

The cellular nature of the Japanese JIT it could be argued, is based on the GT principles. It points to the Japanese success in adopting the best features of the post war Western manufacturing techniques, to their own environment.

The simplicity of the cellular plant layout and product grouping features of GT, along with the dominance of MRP/MRP II systems as the main production and inventory planning and control system in the Western industrialised countries, has led to the development of another category of hybrid systems which incorporate GT and MRP II systems.

5.3 DEVELOPMENT OF GROUP TECHNOLOGY & MRP II HYBRID SYSTEMS

Group Technology, as an area of research, has been a casualty of the MRP crusade of the 1970's and more recently the 'Japanese techniques mania'. GT, as an integral part of systems development can play an important role in manufacturing layout analysis and the development of manufacturing control systems. To date the major utilisation of the many GT facets, remains the grouping of parts into families, and in the determination of numbers of machines required per cell. The appropriate incorporation of GT in an MRP II environment, would as in the hybrid MRP II & JIT/KANBAN implementations, have the advantage of simplifying the control problem through the reduction in the possible permutations of material and information flows, thus reducing uncertainty , which would considerably enhance the chances of successful system implementation, and would simplify its routine production management.

The basic issues in GT relating to potential benefits arising from economies of scale across the family of parts have been discussed in detail by Choobineh (1984), Mosier et al (1985) and Suresh (1979). Mosier, in a discussion on the research potential of GT concluded:

> "Although the theoretical literature dealing with scheduling has been receiving some attention by researchers, ... investigation into the integration of GT with production planning and control systems, such as MRP, is another area where little research has been performed..".

Hill et al (1986), described the successful implementation of cellular manufacturing systems in Lucas Electrical Ltd., in U.K., utilising an MRP II system for the coordination of the production activities. The achievement of more predictable throughput times, and minimising the number of variables which need to be controlled, led to the simplification of the production control function. Hyre et al (1982), discussed some of practical reasons of such an integration in a paper entitled:

> "MRP/GT: A framework for production planning and control and cellular manufacturing.".

They stated that:

> "One way to look at the relationship between MRP and cellular manufacturing is to observe that MRP is a system for order scheduling and, as such, is not concerned with how the orders are completed. Cellular manufacturing, however, is a way of making production more efficient and is therefore not directly concerned with the timing of jobs that pass through the system.". .

The use of production cells, the paper argued would result in shorter and more predictable lead times due to:

(1) reduction in queuing time;

(2) reduction in set up times, and;

(3) decrease in transfer time due to the proximity of machines coupled with the use of transfer batch quantities smaller than the lot size (i.e., use of overlapping).

> "Such short and predictable lead times are very desirable in an MRP environment and allow more accurate time-phasing of component-part planned order releases.".

Ham et al (1978), again explored this issue describing the hybrid system of MRP and GT as:

> "An integrated methodology for production control.".

They further detailed the process of implementing the above, recommending a step by step approach to integration. A more comprehensive hybridisation of GT and MRP was discussed by Mahany et al (1977), in a paper entitled:

> "GT and MRP: An unbeatable combination.".

The integration was achieved through additional dedicated modules to the MRP II system . The paper highlighted the operational advantages of such a hybrid production planning and control system. The basic scheduling process would be as follows:

(1) the MRP II system's master production schedule would indicate an item requirement. When the item required is to be released;

(2) the GT part of the system will carry the release back to the item master file, examine the family containing the item, and make an economically based decision on whether to release an order for an

economic number of parts in the group for some periods ahead, or to release an order of the lot size of the item required.

The result would essentially be a broad lot sizing technique. The part required is lot sized, and GT would cause the order for other parts in the family, (if it is considered economical). The addition of a GT item master file to the basic MRP II system attempts to find economies of scale within the GT cells from a range of orders within a specified time scale.

It should be noted that this approach to hybridisation suffers from the incorporation of the discredited EOQ formula. As it was discussed earlier (chapter 3) the notion that there is such a thing as an economic batch size simply leads to excess WIP and long delivery lead times. GT therefore, has not been hybridised with MRP II system to produce a radically improved alternative. Even cellular plant layout can be congested with work in progress if large batches are considered economical. The above hybrid system suffers from a lack of a global view of economics of an enterprise. The wrongly received locally optimum solutions do not facilitate a smooth flow of goods between cells.

5.3.1 REVIEW OF HYBRID MRP II + GT IMPLEMENTATIONS

It can be argued that the centralised methodology of MRP II system acts counter to the inherent philosophy of Group Technology which attempts to localise decision making and management of production process through simplification of routing and reduction in the number of data elements. Greene et al (1984), in a review of cellular manufacturing assumptions, advantages and design techniques wrote:

> "Cellular manufacturing is the physical division of the functional job shop's manufacturing machinery into production cells. Each cell is designed to produce a part family. A part family is defined as a group of parts requiring similar machinery, machine operations, and/or jigs and fixtures. The parts within the family are normally transformed from raw material to finished part within a single cell."

It was further stated that the following are the main advantages associated with cellular manufacturing:

(1) reduced material handling;

(2) reduced tooling;

(3) reduced set-up time;

(4) reduced expediting;

(5) reduced in-process inventory;

(6) reduced part makespan;

(7) improved human relations;

(8) improved operator expertise.

The latter two advantages are generally said to be the result of shopfloor autonomy and involvement in the manufacturing planning decision making processes. This desirable feature of the GT approach would be negated through the centralised conventional MRP II methodology. If the operators are told, what to make and when to make it, without any involvement in this function, it would act counter to the realisation of the full GT potential.

Apart from the inherent problems associated with current MRP II systems, imposition of centralised control over the coordination of production planning, does not materially help the cell manager in the execution of routine production planning functions such as capacity planning. The conventional MRP II systems approach therefore, does not complement the GT philosophy since its centralised nature removes a major part of the production planning decision making process away from the shopfloor cell managers without providing any enhancements to the local cell management functions. Such a hybridisation introduces unsatisfactory compromises into the configuration which does not fully utilise the potential benefits of the GT philosophy.

Research in the area of hybrid systems development needs to be philosophically coherent and integration should only be considered where there are genuine benefits to be gained and where the total system results in global improvements in the operating performance of the industrial environment for which it is being developed.

5.4 CONCLUDING REMARKS

The hybrid systems which were discussed, have effectively demonstrated that the integration of the relevant techniques to solve a specific type of production planning and control problem can result in improved overall performance. It can be argued that the hybridisations discussed above, have been the result of practitioners seeking solutions to specific types of industrial production and inventory planning problems and lack an overall philosophical framework from which other industrial environments could directly benefit.

The just in time philosophy of manufacture has been incorporated in MRP II/JIT systems in environments where repetitive manufacturing justified its implementation. Others, mainly batch manufacturing industries, have attempted GT/MRP II hybridisation to improve their performance through cellular plant organisation. The former would not apply in all the manufacturing environments and the latter, as was discussed earlier, is an unsatisfactory compromise which does not sufficiently capitalise on the potential advantages of GT principles.

Furthermore, MRP II implementation, judging by the high level of reported failures, has not proved to be a total systems solution to the production planning and control problems. The weakness of the MRP methodology was highlighted earlier, It is therefore argued any hybrid system which utilises a conventional MRP II software, has those weakness incorporated in the system, thus compromising the new hybrid systems performance at its conception.

It is further suggested that the basic principles of Group Technology, have been the seedcorns of the Japanese JIT philosophy. In particular, the cellular manufacturing plant layout and organisational structure and the unidirectional flow of materials.

The incorporation of those principles, in a new hybrid philosophy, would therefore, be a logical and evolutionary step in the right direction. The computerised production planning and control mechanism of any new hybrid system however, should allow the full potential of GT to be realised. Since the existing MRP II methodology offers little scope in that direction, a more appropriate operational methodology would need to be developed preferably, building on the investment in system development and management education which has been lavished upon the now commonly available MRP II software. Indeed an authoritative survey, Anon (1988), in Industrial Computing Magazine carried out in the 1988, concluded that 70% of the industries will have implemented an MRP II system within the next 5 years.

Clearly the computer sales persons and software houses still manage to convince the industrialist that MRP II is the solution to their control problems. The next chapter will outline the arguments for the development of a new manufacturing planning and control philosophy which would attempt to construct an effective and coherent approach to production management to facilitate a successful transition into an integrated manufacturing culture.

CHAPTER 6 THE DEVELOPMENT OF A HYBRID PRODUCTION PLANNING AND CONTROL PHILOSOPHY

The discussions in the previous chapters highlighted the major drawbacks of the existing hybrid manufacturing control systems. This chapter will set out the arguments which led to the development of the Distributed Manufacturing Resources Planning (DMRP) philosophy.

6.1 THE CASE FOR A NEW HYBRID CIM PHILOSOPHY

It is suggested that the reason for hybridisation in systems development should rest on the argument that, the overall attributes of the integrated system should allow the strengths of each incorporated element to be fully exploited and through additional enhancements, the shortcomings of each element mitigated, thus creating a management control system which would facilitate the realisation of the global aims of the enterprise.

The ideal attributes of a production and inventory planning and control system would depend on the particular manufacturing environment for which the system is being designed. However, flexibility, simplicity, ease of implementation and affordability, according to a recent Industrial Computing Survey, Anon (1988), of manufacturing company managers, are the major attributes which the industrialist would ideally require from their control systems. To date it is argued, the traditionally rigid segregation of disciplines across the manufacturing organisations, has resulted in the development of numerous systems solutions within the functional boundaries. These include optimal marketing techniques which have no link to the manufacturing capabilities of an organisation, shopfloor incentive schemes which lead to apparently optimal production of goods which too often lead to excessive inventories, and misguided measures of productivity which result in uncoordinated utilisation of productive resources with the inevitable consequence of customer dissatisfaction, Wheatley (1988).

The hybrid systems which attempt to simplify the production planning process through the incorporation of Kanban cards with the MRP II systems have demonstrated the need to accept the shortcomings of MRP II systems and, instead, attempt to enhance their positive characteristics.

It is argued that in any manufacturing organisation, the two broad areas of control could be defined as the manufacturing plant and management support services required to coordinate the material supply and marketing of the goods and services. Bearing in mind the ethos of profitable growth should be the main objective of any manufacturing organisation, a simple analysis of the control problem could be initiated.

Isolation of the manufacturing plant control problem, simplifies the basic argument which starts with the following supposition; the simplest manufacturing planning plant would consist of one machine which would process from a raw material a single product into an unlimited market demand environment. The only concern would therefore, be to ensure the timely supply of raw material and whenever possible, reductions in the cycle time to increase throughput thus maximising profitability. The bill of material would contain one level and the routing could not be more simple. This utopian control scenario however, is evidently rarely encountered in the real world manufacturing environments. Instead, the various control systems attempt to coordinate a large number of manufacturing resources containing complex BOMs and routings which in turn require numerous components and raw materials.

This common phenomenon has partly arisen due to a incoherent, and in some cases separate, implementation of new manufacturing processes from the shop floor management control systems. One explanation for this approach has been that a good manufacturing planning and control system would cope with any manufacturing process that a company may choose to employ. It is suggested however, that existing production planning and control systems tend to impose their own restrictions on shopfloor management simply to make such systems operational. The traditional centralised MRP II systems for example, have imposed a discipline on the manufacturing plants with regards to work orders and the timely manner in which they should be released, whilst in a majority of cases relying on out dated or arbitrarily inflated lead time data in suggesting these timely releases. Furthermore, with basic regenerative MRP II systems (which are most commonly implemented), the frequency in which this kind of information is dispatched is necessarily limited to once a week or once a month, due to the lengthy data processing requirements of such systems and the lack of database access to other users such as Finance, Sales, Manufacturing and Purchasing departments during the MRP runs. Therefore, a solution which potentially improves the operational management of a plant and provides data upon which other departments rely on to do a more professional job, has introduced a series of limitations.

Over the last two decades the practitioners have largely accepted the latter scenario as a fact of life and with the aid of the computer manufacturers persuasive touch, have come to the conclusion that the problem of coordination is too large a logistical problem for management to hope to tackle. Therefore, computers should be utilised to carry out these computational tasks, leaving the management to oversee the broader requirements of the organisation.

The evolutionary transformation of material requirements planning (MRP) from a largely effective inventory planning and control system into the Manufacturing Resources Planning (MRP II), could be cited as a product of the overwhelming enthusiasm for computerised manufacturing system solutions. Current literature suggests that piecemeal integration of locally optimum solutions into a company-wide integrated system, can lead to the creation of a logistical burden. The ever increasing concentration of data into a central computer data base in MRP II system implementations (ignoring for the sake of argument the methodological shortcomings of the system) inevitably leads to data processing bottlenecks which in turn lead to the need for more powerful computers to overcome the newly created problem, as well as, the original production planning and control problem, which the system was supposed to solve. Needless to say the principal benefactors in this era have been software houses and computer manufacturers. Even if the data processing power of the computers were increased, the centralised planning and top-down operational methodology of the MRP II systems are two important inherent weaknesses which, would mitigate against improved production and inventory planning and control.

The dynamic nature of the manufacturing plant, is not reflected in the calculation of suggested manufacturing start and required dates. To compensate for this shortcoming, the lead times are invariably adjusted (it could be argued inflated) to cover the worst loading conditions on the shopfloor. This unsatisfactory compromise which results in longer than necessary overall product lead times and excessive levels of work in progress, is as a direct result of the MRP methodology, and therefore, independent of the processing power of the host computer.

It is therefore argued, that unless the fundamental shortcomings of the methodology are resolved, new developments in computer technology in themselves do not provide any improvements in the overall performance of the manufacturing companies which utilise any type of MRP/MRP II systems as their main management control system.

The growth in the number of articles in the professional journals suggesting solutions other that MRP II systems, it could be argued, is a testimony to the realisation that computer power does not in itself solve the manufacturing control problem.

6.2 DISCUSSION OF CURRENT COMPUTERISED MANUFACTURING CONTROL SYSTEMS

The number and complexity of the transactions involved in calculating material requirements very often limits the frequency of recalculation (MRP runs) to one per week and in certain cases, even one per month. Furthermore, every regenerative MRP run may take many hours of dedicated computer processing time, which has to be performed when all other activities have ceased (e.g., at the weekend or overnight). This constraint may seriously impair management's ability to analyse and respond effectively to the changing circumstances.

The use of the system to support 'what if' analysis in relation to master production scheduling or detailed capacity planning is usually equally constrained. The length of the MRP recalculation is dependent on a number of factors but is particularly related to the size of the manufacturing database and hence the number of live inventory items held on the system.

The process of closing the loop is also constrained by practical problems. For example, it may be difficult to identify which entries in the MPS are responsible for workstation overloads evident from the capacity requirements planning (CRP) analysis of suggested works orders. The complexity of the bills of material together with the effects of commonality and lot sizing make the classic MRP II process difficult to achieve without load pegging facilities, (which add more complexity to the existing complex centralised software structure).

A rough-cut type of capacity planning is often performed within the MPS module, to reduce the effects of lack of load pegging, prior to a full MRP run. CRP is then used to drive short term capacity adjustments. Rough-cut systems have the advantage that they provide a direct link with an MPS entry and the load it generates. In addition the simplicity of the calculation allows much faster execution of the analysis. However, since most systems consider only key resources and ignore all stocks and work in progress, precise load analysis cannot be produced using this technique.

Net change systems can recalculate requirements (i.e., do an MRP run) much faster than the regenerative systems, provided that the magnitude of the changes that would trigger the re- calculation is not too large. To operate such a system effectively, a net change form of capacity requirements planning would also be required to carry out 'what if' analysis.

Clearly the facility to evaluate the validity of the MPS is critical in any MRP II system since the requirements calculation itself ignores capacity constraints. The start and required dates as was stated earlier, are calculated on the basis of fixed lead times which take no account of the transient capacity/loading conditions at dependent work centres. Even when an attempt is made to calculate the lead time offset, MRP systems merely add up the total processing time and add an arbitrary (fixed) queuing allowance which in no sense could be described as the best estimate of actual lead times.

The current computer based (centralised and top-down) production scheduling and control systems dominant in the Western industrialised countries, unlike the bottom-up Japanese approach, remove much of the important decision-making from the shop floor. But nevertheless, to function successfully, they are dependent upon timely and accurate feedback of shop floor performance data. Leaving aside the important psychological effects (i.e., demoralised and unmotivated shop floor personnel, and all its negative implications on quality issues), in all such systems it is difficult to implement the concept of ownership.

A manager who perceives a system or subsystem as being under his/her sphere of control is more likely to operate it effectively (maintaining the integrity of the system) and thus be committed to its successful operation. It is therefore argued, that managers are more likely to feel in control of the computer generated action plans if the computer systems were within their span of control and responsibility.

The size and scope of most computerised production control systems however, can lead to a perceived lack of 'ownership' and thus lack of overall control by the people who are responsible for the day-to-day operation of the plant. The above applies as much to MRP/MRP II systems as the OPT software. The potential difference being in the manner that the schedules are generated. The lack of ownership is even more pronounce in companies which have implemented OPT software, where the detailed schedules are generated and the shopfloor managers simply follow instructions. Given the state of knowledge about production planning and control systems, it is argued that such centralised, top-down systems suffer from lack of involvement by the key shopfloor personnel and thus could not be considered a satisfactory approach to production planning and control systems for the future.

It is suggested that, large problems tend to attract large scale solutions which in turn tend to bring in with them inflexibility, lack of user control, massive system inertia and very high overall implementation costs. Japan has often been hailed as the country which seems to be able to cope with every world economic cycle better than the Western industrialised countries. Some of the fundamental characteristics of their approach to management are simplification , standardisation, delegation of responsibility to small units of autonomous local managers and an uncompromising philosophy of ever increasing quality and productivity through the encouragement of local managers to view any change which would lead to improved performance as desirable.

The simplification of the control problem has been achieved to good effect through the adoption of the cellular plant layout and Just In Time production methodology. The same cellular concepts in the West however, have suffered from inappropriate use of centralised production planning and control systems. It is suggested that some form of decentralised planning and control system, if applied to cellular plant environments would result in a more flexible and operationally simple approach to manufacturing control. Love at al (1986), in discussion on distributed Computer Integrated Manufacturing systems wrote:

> "The characteristic of cellular systems which leads to simplification of the control problem would appear to have obvious benefits in application to CIM. The acceptance of cellular principles leads inevitably to the decentralisation of all the major control functions. Each cell can be provided with a range of facilities to suit its particular needs. The complexity of

> the local control system is much less than is implied by a conventional centralised approach. Simplification of the system software and database structures leads to a consequent reduction in development time and costs."

Complex production planning and control systems offer the user a multitude of policy choices but their very size obscures the cause-effect relationship which is vital to appropriate selection of available options. The impact of local decisions, for example rescheduling a job, is difficult to determine on the whole system. Conversely, the effect of a high level policy decision, perhaps relating to material requirements planning or lot-sizing, on work centre loading, would require extensive analysis.

6.2.1 DECENTRALISED PLANNING AND CONTROL SYSTEMS

The Japanese Kanban system has received much publicity in recent years owing to its undoubted success in achieving impressive reductions in throughput time and work in progress, Finch et al (1986) and Kempa et al (1986). Unlike the centralised systems, Kanban with it's cellular layout and bottom-up approach to planning, can be considered as a decentralised/distributed production planning and control system. The system is designed to detect and solve problems locally. All the key resource control mechanisms operate at shopfloor level. Of course the simple control procedures that Kanban uses only works well when the environment has been set up to exclude major sources of uncertainty. Hence practitioners emphasise the importance of levelled MPS scheduling, zero defects, reliable plant and other factors intended to limit the fluctuation (planned or unplanned) that the system has to endure. Whilst many of the Kanban prerequisites could profitably be adopted in any

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Kanban in some manufacturing industries. The batch manufacturing environment, where the nature of the business imposes a large degree of variability in the product specifications and the manufacturing processes involved, is a particular example which would not satisfy the environmental prerequisite of the Kanban approach. However, this does not imply that the cellular plant layout, autonomous local decision making and bottom-up planning and control could not be implemented in such an environment.

The existing centralised production planning and control systems would clearly not be suitable, but a decentralised/distributed approach could be developed which would allow the majority of the benefits of the Kanban approach to be realised whilst accommodating the specific demand characteristics of the batch manufacturing industries. In this respect the MRP systems due to their ability to work under most industrial environment, if scaled down to control each cell instead of the total plant, could represent a potentially flexible starting tool in the development of a decentralised/distributed production planning and control system. The following section will briefly discuss the principle of distributed planning and control.

6.2.2 THE PRINCIPLE OF DISTRIBUTED PLANNING AND CONTROL

The disadvantages of the computer based centralised production planning and control systems, in particular the MRP/MRP II and OPT systems were discussed in detail in the preceding discussions. It was also suggested that if a computer based decentralised/distributed approach incorporating the cellular concepts (which were successfully adopted by the Japanese industry) could be developed, those major disadvantages could be negated. The following discussions will briefly outline the basic principle of distributed planning and control.

The term distributed planning and control in relation to the attainment of decentralised management control systems, though well established in the Japanese management control thinking, has only in the last decade been seriously mooted as a viable alternative to the centralised management control techniques.

The recent acceptance of the decentralised/distributed control, it is argued, owes a great deal to the developments of distributed data processing technologies utilising computer networks which permit data to be shared and separately processed. In the data processing context, data is distributed and processed across a range of computers. However, it does not necessarily follow that the management functions and responsibilities or the physical manufacturing processes are distributed. A decentralised/distributed approach to production planning and control when referred to in this thesis, has a much broader definition than that of computer data distribution which would vary according to particular applications. In fact it is possible to implement decentralised/distributed management systems by distributing data within a central database/file server utilising a computer network and a number of distributed computers which would access and process their own specific functional database, as well as common databases held on a centralised database/fileserver and still achieve the characteristics of distributed control.

6.2.3 ADVANTAGES OF DISTRIBUTED DATA PROCESSING

A distributed system is one where an application can be processed dynamically on multiple processors, where the processors are distributed across many locations or nodes through a local or wide-area networks, Hares (1988). The ability to provide the various functions within an organisation with their own computer processing and data sharing facilities, reduces the dependence on an often unresponsive Data Processing department. Hares wrote:

> "The facilities offered by distributed database software mean changes are occurring in the way that information is handled and business is conducted. The days of monolithic, all powerful, centralised data processing department are over. The growing user-friendliness of data-software is increasing the independence and power of managers and users in using and developing information systems. Because of long lead-time and back log in the DP department for developing application systems, many have gone their own way and created their own personal systems on PC's."

The technical workings of the distributed databases and distributed processing are not within the remit of this thesis, however, Lung (1988), Hodgson (1986), Timm (1981), Shaw (1987) and Houten (1986), describe the mechanisms in detail. The suggested advantages of distributed data processing in the context of decentralised management systems are:

(1) improved efficiency in system control;

(2) further enhancement of system flexibility in the decentralised functional areas;

(3) faster localised data processing;

(4) improved response to new decisions or changes;

(5) capacity to simplify and rationalise complex tasks in an integrated environment and reducing the amount of data in process at any one time;

(6) improved management control over functional areas;

(7) data accountability would lead to increased data integrity across the whole of the management control system.

6.2.4 DECENTRALISED CONTROL AND CELLULAR MANUFACTURING SYSTEMS

Classically, cellular concepts are associated with the Group Technology (GT) approach to design of manufacturing systems, Huang (1985). In more recent years, FMS represents a technically more sophisticated implementation of cellular principles. The cell manager may be regarded as the 'owner' of a manufacturing business unit (the cell) and may be measured against broader performance objectives than would be common in conventional manufacturing plants, Greene (1984). The opportunity may also be taken to strengthen the cellular structure by decentralising functions such as quality control, works engineering, industrial engineering and production planning.

Major benefits have been claimed for the application of cellular concepts specifically in relation to reduced throughput times and work in progress, Burner et al (1970). These improvements arise from a number of factors including aspects such as improvements in motivation and management accountability. However, the single most important factor is the cellular systems's ability to simplify the nature of the manufacturing control problem. Breaking the manufacturing system down into small tightly controlled units simplifies the material and information flows between cells. Many of the control functions can then be performed entirely within the cell and require no external interactions.

The issues relating to the development of successful scheduling systems in both functional and cellular systems have received considerable attention, Baker (1979) and Connolly et al (1970). However, the calculation of material requirements appears to have received relatively little attention. Actions in this respect have concentrated on modifications to MRP systems to include family recognition and to simplify work in progress tracking requirements, Hyre et al (1982), Greene et al (1984) and Suresh (1979).

Cellular systems offer an opportunity to improve manufacturing performance even in circumstances unsuited to the application of Kanban or other simple material control and planning systems. In industrial environments which are subject to dynamic demand patterns, high product variety and/or low volume, conventional solutions would be to use MRP or perhaps OPT. However, both of these alternatives fail to fully capitalise on the potential offered by cellular organisations. The thesis suggests that a decentralised approach could unlock the potential of the cellular systems.

6.3 CONCLUDING REMARKS

Historically the production planning and control function had evolved around small and largely informal organisational structures where the control aspects were not a major issue. Clearly the fact that a product was on the whole manufactured from start to finish by a craftsman or at least under the supervision of a craftsman was a positive contributing factor. But as Jackson (1978), in a discussion on cellular systems highlighted:

> ".. as organisations grew in size they became too large to be controlled by a single person and specialist control sections began to develop. As the cost of products became more important, accounting procedures were developed and with company growth, increasing levels of sophistication were reached until it often became apparent that the costing procedures had become the main priority, not the production system as a whole; and the amount of paperwork tended to restrict output.".

It is suggested that a further damaging consequence of the above development has been the a deterioration in the overall quality standards. He further pointed out that :

> "The emphasis on cost control has also contributed to the reduction in the general quality level of products since originally the skilled craftsman built his individual unit with great pride and satisfaction, and any sub-standard article reflected upon him personally. Now however, in the cause of greater efficiency, work has been broken down into smaller elements and with much of the job satisfaction removed, it is only natural that the general interest in quality has declined and greater emphasis has had to be placed on inspection procedures...The concept of 'economies of size' has become rather dubious in certain sectors of industry, since growth has restricted communication and presented a production control problem. When human control of flow of work became impossible, even with an army of progress chasers, attempts were made to superimpose control by computer, but the failure to realise that the real situation is dominated by unpredictable decisions, changes, omissions and errors at the shop floor level rather than broad advance planning, brought the systems into disrepute.".

He also highlighted the fact that the development of specialised departments has led, in certain cases to the creation of complex organisational structures with extended lines of communication and a large number of individuals each concentrating on their own function. Thus problems tend to be submerged until a crisis level is reached and opinions are so hardened that an early solution would be difficult to obtain. He concluded that:

> "The designers of production systems must plan for the maximum efficiency which is essential in a competitive society, but not by sub-optimising one factor at the expense of the others. The economic, technical and social aspects of the internal environment being created must be considered, but the necessity for effectiveness in external environment must not be forgotten: by this process the production system will become a competitive asset, not the corporate millstone it so often is."

In bringing this chapter to a close, the thesis would point to McGregor's theory Y, Lupton (1971), in which he stated that:

> "People will work effectively and happily together if they take part in setting work standards for tasks which catch their enthusiasm and engage their talents; they should also be able to help create and develop the working environment ...".

The above statement has been an important element in the development of the distributed MRP philosophy. Jackson's conclusion in relation to the design of manufacturing systems was:

> "In order then to make maximum use of our valuable asset, labour, we need to maintain the correct environment, both socially and technically, so that man will function at his optimum and contribute towards the company goal in an economic production system whose efficiency contributes to the prosperity of all concerned.".

The following chapter will introduce the Distributed Manufacturing Resources Planning philosophy, describing its operational methodology and broad range of advantages over the centralised MRP II systems.

CHAPTER 7 INTRODUCTION TO THE DISTRIBUTED MANUFACTURING RESOURCES PLANNING PHILOSOPHY

The discussions in the preceding chapters have attempted to highlight the limitations of the dominant production planning and control systems, in the western industrialised countries. They further suggested that the Japanese Just In Time (JIT) philosophy and the Kanban system in particular, are only applicable to industrial environments with high volume stable demand conditions. It would however be wrong to dismiss the JIT philosophy as a whole, as being limited to specific types of industrial environments. An analysis of the basic constituents of the philosophy, would highlight the following main features:

(1) Cellular plant layout;
(2) Local autonomy;
(3) Bottom-up planning;
(4) Just In Time manufacturing;
(5) Simple to operate and easy to understand.

The above features of the successful Japanese approach to design and development of manufacturing control systems, are individually independent of each other. The adoption of cellular plant layout and bottom-up planning, for example, are not dependent upon a stable product demand. The incorporation of such features in the design and development of new manufacturing control techniques, for a wider range of industrial environments therefore, should be considered.

The massive investment in the MRP/MRP II systems, over the last two decades, have yielded relatively poor returns. Yet the trend towards their adoption in manufacturing industries shows no sign of slowing down and the number of successful implementations, judging by a recent Industrial Computing survey of UK manufacturing industry, have remained low, Anon (1988). It was suggested earlier, that the trend is unlikely to change, since the MRP/MRP II methodology is inherently prone to failure. Furthermore, the centralised computing structure and the use of a large centralised database have resulted in data processing bottlenecks which have added to the burden of successfully implementing an MRP/MRP II system.

The review of the existing systems, points to a need for a coherent approach to the design and development of such systems. It is suggested that any new approach should contain the following characteristics:

(1) Conceptually simple to understand and operate;
(2) Shopfloor autonomy;
(3) Bottom-up planning;
(4) Applicability to a range of industrial environments;
(5) Utilisation of existing investments in systems and user education;
(6) Capacity sensitivity;
(7) Facilitate manufacturing integration;
(8) Affordable and easy to implement;
(9) Flexible to reorganisation and changes in the manufacturing environment.

The literature suggests that one of the main reasons for the success of the Kanban system, is the simplicity of the concept. There are no vague rules and exceptions in operating the system. The simplicity was from the outset built into the system, by the Toyota design team. The design of a new concept which would be applicable to a wider range of industrial environments, should attempt to build into the system the characteristics which would make it easy to understand and operate across the range of functions within an organisation.

A common problem with current computerised systems like the MRP/MRP II and the OPT systems, is the fact that the DP department is seen to be telling the shopfloor what they should do. This situation not only creates an air of apathy, but it leads to difficulties in implementation. If a machine breaks down, the first people to know about this fact are the shopfloor. However, the centralised nature of such systems with their top-down approach to planning and organisation, except in technical areas, do not allow for shopfloor personnel to decide the best course of action. The sad truth is that the course of action open to the senior managers is often the one that the shopfloor personnel by virtue of their experience, would instantly recognise. A bottom-up approach to manufacturing management would, it is suggested, improve responsiveness to problems. The Japanese have demonstrated that the positive effect of shopfloor involvement, is not confined to indigenous workforce, when they successfully operate plants in regions of UK which were once notorious for having so called "militant" workforce. Shopfloor autonomy in decision making along with clearly defined responsibilities, should therefore be included as an objective in the design of new manufacturing control systems.

The centralised systems, as it was stated earlier, have a top-down approach to planning. The alternative to this approach, is to develop a system which is intrinsically bottom-up. This approach would involve the shopfloor personnel to exercise autonomy about the best course of action across a range of management functions. These could include production planning (given appropriate tools and training), quality control and decisions regarding unforeseen shopfloor events.

Leaving aside the problems associated with the existing computerised systems, a positive feature of them lies in the fact that at least conceptually they can be implemented in a wide range of industrial environments. Any alternative approach should therefore, attempt to achieve this objective.

With the advent of computerised manufacturing control systems, a great deal of investment has been absorbed in the education of industrialists and in the development of such systems. As a result, computers have been recognised as potentially useful management tools. The acceptance of MRP/MRP II systems and their availability across a wide range of computers, for example, represents both an opportunity and a dilemma. The opportunity lies in their availability at relatively low cost and familiarity to potential users, as the accepted norm. The dilemma on the other hand, lies in the fact that as they stand, they are unlikely to yield much return to those organisations which intend to implement them. The opportunity therefore exists to capitalise on such systems by tailoring them in such a manner that would remove their negative characteristics.

Manufacturing integration to rationalise and exploit opportunities for expansion, the literature suggests, has become an important goal of manufacturing organisations. The ability to achieve this goal therefore, should be incorporated in the design of new systems.

The problems associated with the implementation of existing systems, is often blamed on bad project management. Whilst this is often the major cause of failure, it does not hide the fact that such systems by nature must be difficult to implement. The ability to easily phase in the system, is another important characteristic which must be a design objective.

7.1 THE PRINCIPLES OF DISTRIBUTED MRP

Distributed MRP philosophy is a hybrid production and inventory planning and control concept which incorporates the basic Group Technology principles of cellular plant, organisational structure and decision making autonomy, as well as a newly developed decentralised, capacity sensitive, distributed MRP methodology. At this juncture it should be noted that DMRP is not in any way connected with distribution resources planning DRP, Martin (1983), which is concerned with the control of distribution networks.

The cellular plant layout does in effect allow the creation of small autonomous manufacturing plants within a larger manufacturing company. If we suppose that each cell could then utilise a micro based MRP II system to plan its production schedules, the basic features of each system would include:

(1) Local system ownership and responsibility;
(2) Local computer processing facility;
(3) Simple production routings;
(4) Generally single level bill of materials;
(5) Relatively small number of data elements;
(6) High data integrity;
(7) Small number of work stations;
(8) Few easily identifiable bottlenecks;
(9) Simple local capacity analysis;

Each cell would own its own independently operated micro based MRP II system. This facility would allow the cell manager to utilise the system to the full, without having to wait for the D P department to sanction an MRP run, (which the literature suggests, is likely to be no more than once a week).

A cell organised to manufacture a specific family of products, would have simple production routings and mostly single level bill of materials. This in turn would lead to relatively small number of data elements for the MRP II system to process. A simple local database would therefore be sufficient to store all the relevant data. A further significant advantage of this approach would be that maintaining the data accuracy of the system, would be the responsibility of the cell manager who would know when a production route was changed and which components are no longer used in the production of the family of products. Data integrity of the system would therefore be high.

The creation of small autonomous manufacturing cells, would result in a limited number of work stations with highly visible sources of transient bottlenecks. The assessment of the levels of transient capacity would subsequently be greatly simplified. It is therefore suggested that such a system would be locally capacity sensitive. Ideally however, the total manufacturing plant, would need to be under a coherent and integrated manufacturing system. To overcome this negative aspect of the above approach, let us assume that each cell could in some form be linked to all the other cells in the factory, to create an integrated system. The system would still need to be refined further, before it could be described as globally capacity sensitive and the mechanism under which it would operate, would require further enhancements.

The advantages of distributed processing have increasingly been discussed in the literature. Shaw (1983), suggested the use of distributed planning in cellular flexible manufacturing systems. Weston et al (1986), described the use of distributed processing in the context of distributed manufacturing systems. Hares (1988), discussed the growth in the use of distributed data processing specially in retailing and distributions networks. Lung (1988) however, in a discussion on distributed Computer Integrated Manufacturing systems, suggested that the manufacturing cells should have their own MRP II system. He further suggested that the top-down centralised methodology of the existing MRP II systems could be replaced by cascading down the requirements to each dependent cell. This approach would allow the computer processing to be distributed across the dependent cells, thus removing the data processing bottlenecks associated with centralised MRP II systems. However, this approach could not be described as a globally capacity sensitive system. Furthermore, by using the existing MRP methodology, the problematic use of fixed lead times would still continue.

The DMRP approach recognises these shortcomings and suggests two enhancements to the cascade process, which would result in a globally capacity sensitive distributed MRP II system. It should be noted at this stage that the enhancements made to the suppositions of operating a cellular plant with each cell operating its own MRP II system, are unique and original features of the DMRP philosophy.

Essentially the global capacity sensitivity is achieved through the use of a feedback mechanism between the dependent cells. This allows the capacity conditions of the dependent cells to be communicated to the relevant cells, whenever the conditions change. The basic MRP operational methodology has also been changed to remove the need for fixed lead times. This new approach whilst utilising existing MRP II software, through changes in the way they have traditionally been operated and the addition of a feedback mechanism, would it is suggested, significantly improve the characteristics of such system. The mechanism of the new methodology and the feed back mechanism will be discussed in more detail in chapter 8.

The DMRP methodology exploits the cellular plant layout and organisational structure to reduce the size of the production planning and control problem. Basically, a manufacturing plant consists of many production processes utilising various technological and human resources. In a plant controlled through the DMRP approach, the various manufacturing processes are organised in autonomous cells with defined boundaries of function and responsibilities. For example, a manufacturing plant which produces a range of products, would be organised so that each family of products are produced in a cell. From a management control point of view, this approach simplifies the the production scheduling task into a set of visible and easily definable manufacturing resources. The work load and available capacity of each cell can easily be assessed by local cell managers who are responsible for all the decision making. Conceptually, senior managers delegate the manufacturing control function down to the local cell managers who are uniquely qualified to decide how the production process should be organised and depending on the priority of a customer order, when they can realistically start production and when they can deliver.

Incidentally, the delegation of production planning function to the local managers is a prominent feature of the Japanese style of management. Under the DMRP approach, in delegating the responsibility for production planning and control, each cell manager would use a locally owned and operated MRP II system running on a micro computer. The nature of the cell would determine the type of management control facilities which the MRP II system should provide.

The isolation of each cell would allow the cell manager to exploit the MRP II systems features to the full. The delegation of the responsibility to let the shopfloor control and manage their various functions, is therefore matched with providing them with the tools they need to carry out their tasks professionally and efficiently.

Clearly, dependent on the manufacturing environment and the production technology employed, a range of possible cell designs could be exploited. It is however, essential that the cell, as far as possible, be self contained, thus requiring the least amount of support from other cells within the plant. The reduction in the number of dependencies allows for a much more simplified DMRP planning methodology. Experience suggests that the imposition of any production planning and control system upon a disorganised and unfocussed manufacturing plant would not be successful.

The cellular structure makes possible the development of a distributed form of MRP II software implementation. Each cell is provided with its own small (micro computer based) MRP II system. The prototype system developed at Aston University utilised the commercially available UNIPLAN MRP II system hosted on local IBM compatible computers resident in each cell and linked to all other cells via a Local Area Network (LAN). The product bill of materials is distributed across all the relevant cells, each cell holding only that part of the bill which relates to its needs. The cell bill covers only the levels between the input and output stages of the item manufactured by the cell. For example the BOM for an intermediate assembly cell would cover the levels from the assembly through its sub-assemblies to their components, Figure (7.1).

AN EXAMPLE OF DISTRIBUTED BOM

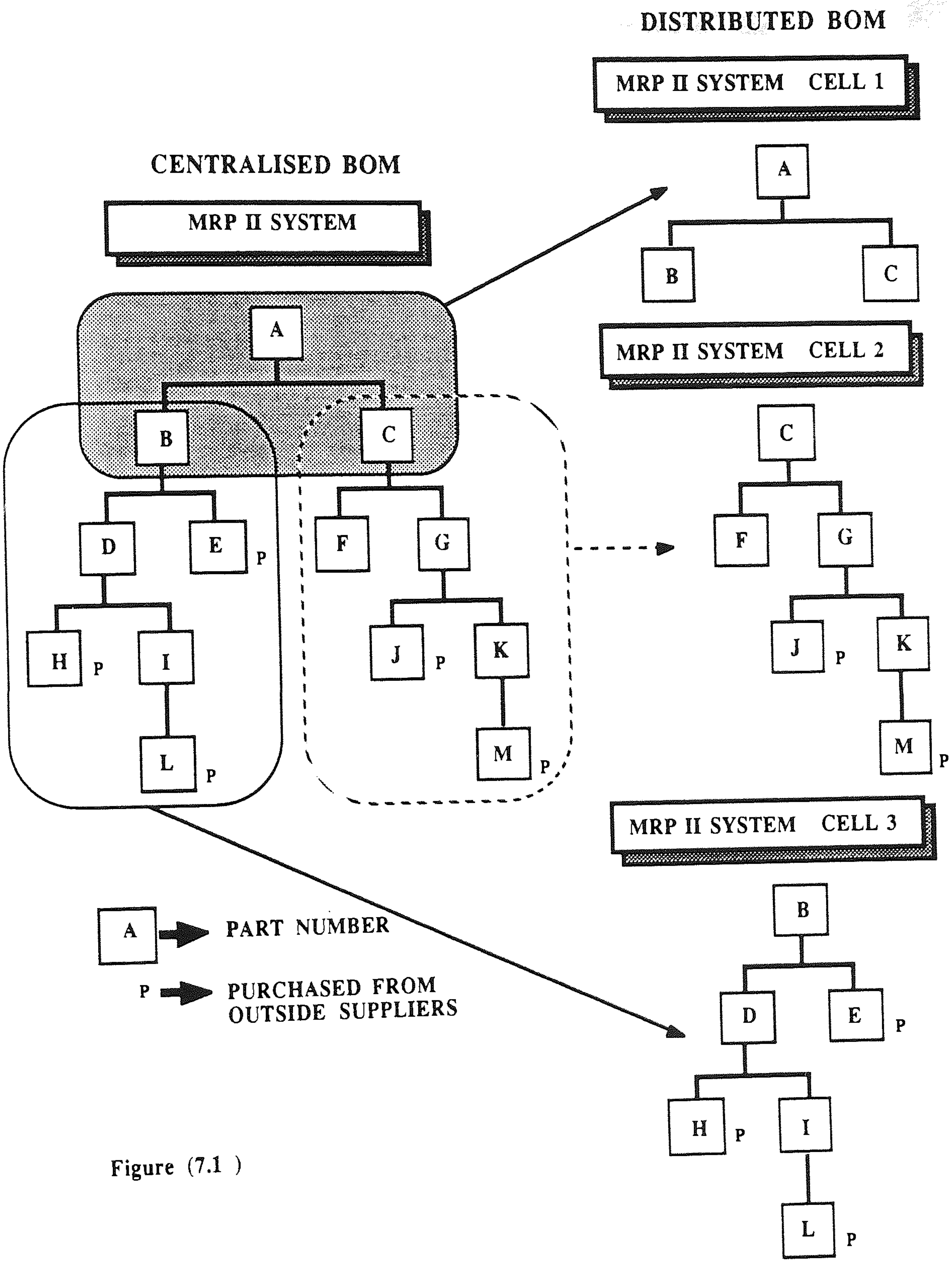


Figure (7.1)

Component manufacturing cells would require only a simple bill linking finished parts with raw materials. The DMRP philosophy would however, recommend that the cell formation process prior to implementation, should attempt, as far as possible, to produce single level BOMs for all the cell products. This reduces the scheduling effort which will be discussed in the proceeding discussion in this chapter. Inventory records are held only for parts manufactured or produced by the cell. The cell also holds all the routing data for its manufactured parts.

7.2 CONCLUDING REMARKS

The characteristics of the DMRP philosophy discussed in this chapter, lead to the development of a prototype DMRP system to investigate some of the practical implications of adopting the concept in a simulated industrial environment. The discussion in the following chapter will introduce the DMRP planning methodology.

CHAPTER 8 AN OVERVIEW OF DMRP PLANNING AND CONTROL MECHANISMS

Unlike the conventional centralised MRP II methodology, DMRP relies on factual and dynamic data from the shopfloor, to determine order release dates. The average lead times and infinite capacity approach of the conventional MRP II methodology is therefore abandoned.

The distributed nature of the data structures, as well as, local independently operated computers, with their own local database, provide a degree of flexibility which the conventional approach of MRP II implementations lack. DMRP removes the need for largely arbitrary lead times, the start and end date of a batch can be determined, depending on the local capacity availability. This unique approach is made possible through the formation of small autonomous cells.

The following discussion provides a conceptual overview of the methodology.

The centralised structure of conventional MRP II systems, in practice tends to limit the number of MRP runs, consequently the shopfloor managers tend to treat the work order's start and due dates justifiably with suspicion. The implementation of an MRP II system with a capacity planning module, in reality does not necessarily lead to the CRP module being fully exploited. This is largely due to computer processing bottlenecks. The MRP runs are often scheduled to take place over the weekend. Therefore, the advantages of MRP II systems over the early MRP systems, in practice lies in the integrated sales order, purchase order, accounting and other company-wide support functions and not in providing capacity planning facilities during the planning loop. The potentially beneficial 'what if' analysis facilities which are available on most MRP II systems therefore, are rarely used. A commonly adopted compromise, is to inflate the lead times to ensure there would be sufficient time to process each job by its due date, leading to increased overall product lead time and excess work in progress inventories.

The DMRP methodology however, dynamically schedules the orders by consulting the cell managers during the planning runs. This allows every cell manager to schedule each work order precisely, based on the existing work load and transient capacity availability of the cell. Only when a feasible production schedule is attained, are the requirements for any other dependent cell passed on. The available capacity information which only the local cell manager can realistically assess, is translated into the scheduling operation, removing the need for average lead time data which are used by the conventional centralised MRP II systems. The technological lead time, which is defined as

'set-up time + (batch quantity * unit production time)

is the only true guide to the manufacturing lead time. However, the start date of any process is dependent on the available transient capacity on the shopfloor, given the existing production commitments. In a DMRP environment, the cell manager is able to make an intelligent decision based on the information which is available to him. This approach will put credibility on the shopfloor schedules as they pass through to the final planning stages and back up to the customer with a realistic and reliable delivery date.

The availability of cost effective micro computers and Local Area Networks (LAN), make this bottom-up methodology a practical and cost effective alternative to the existing conventional, top-down planning systems.

The adoption of cellular plant layout, as it was stated earlier, allows the formation of autonomous cells with a wide range of possible configurations and product part numbers. The important issue to bear in mind, is that the frequency of planning runs is dependent upon the particular plant, manufacturing technology employed and the actual arrival rate of customer orders. Clearly, if a company receives a large number of orders distributed across each working day, then it is important to pool the orders into a series of set time buffers. The number of parts and the number of dependencies (ie the number of cells on the production route), are also considerations which from plant to plant affect the frequency of the planning runs. A further issue is whether the MRP II software is net change or regenerative. The regenerative MRP II software requires more computer processing time than a net change system which only replans order actions for those orders which are new or those which have been rescheduled. Within the overall planning cycle therefore, the processing speed becomes an issue which needs to be resolved.

The practical options would be either to employ high powered computing technology or to compromise on the time taken to carry out the planning runs. In a company where speed of response to the customer order is an important competitive advantage, clearly the former options should be adopted. In either case, the delivery date would have a high degree of integrity built into it and would be the shortest possible lead time in which an order could be manufactured. This again is a unique feature of DMRP methodology which centralised MRP II systems would not be able to match.

8.2 DMRP OPERATIONAL PLANNING METHODOLOGY

The overall system management in a DMRP plant, utilises a plant-wide management cell which is referred to as 'CELL CONTROLLER', figure (8.1). This cell is the main point of contact with the plant's external customers. When an order arrives, if it is a non stock item, the cell controller enters the order as a tentative gross requirement into the cell's MRP II system.

The system contains only single level bills with the final assembly product code and the cell in the plant which produces the final product. The cell controller then executes an MRP run. The suggested purchase order(s) are passed on to the final assembly cell. The cell manager then enters the order as gross requirement. An MRP run is then executed. The suggested work orders are then scheduled, taking into account the existing work load. The start and end date of the work orders are input into the MRP II system and

DATA COMMUNICATIONS IN A DISTRIBUTED MRP II SYSTEM

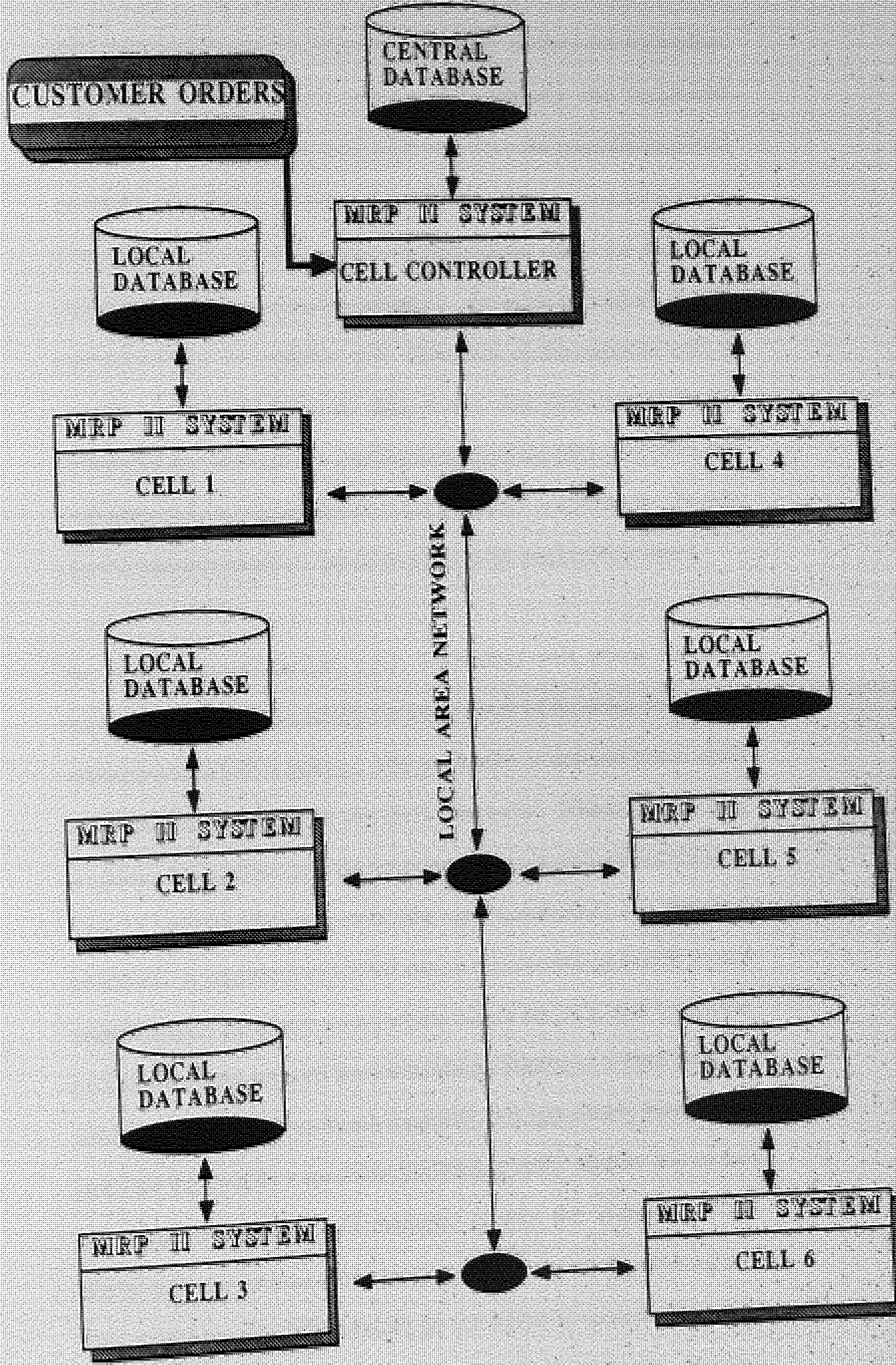


Figure (8.1)

another MRP is executed but this time based on the tentative work orders and not against the gross requirement. if there are dependent cell which need to supply parts or components, the suggested purchase orders which are generated will have the quantity required as well as the due date which the cell manager has just scheduled. The suggested purchase orders are then passed on to the suppliers cells to plan their production schedule. the same procedure is then carried out by the supplier cell. However, if the supplier cell is unable to meet the required date, a new due date is tentatively scheduled and through the feed back mechanism passed back to the customer cell to reschedule the cells schedule accordingly. In this manner the schedules are based on achievable and realistic dates.

As it was stated earlier, each individual cell plans its own requirements using essentially the same range of facilities found in a conventional MRP II system. The local MPS is defined based upon 'sales orders' received for the cell's 'products'. These orders may originate from other cells (ie for components or sub-assemblies) or from a central planning unit (the cell controller) for finished products. A conventional MRP run is executed to generate works orders, which authorise manufacture within the cell, and 'purchase' orders' for items sourced from elsewhere.'Purchase orders' become 'sales orders' when they reach supplier cell (genuinely bought-out parts are handled by a specialist purchasing cell). Before any orders are released the local cell manager checks the viability of the production programme using an appropriate capacity planning aid. This could be the CRP module in the MRP II system, a simple planning board with the production plan indicating loading conditions or a sophisticated finite scheduling tool. The lead time data is calculated based in the technological lead time and the production schedule is produced based on nearest available time when capacity would exist to carry out the manufacturing operations, given the existing mix of production. If problems arise the local MPS is rescheduled and the process repeated until a satisfactory compromise is attained.

The rescheduling and the number of MRP runs required to produce a realistic schedule, does not affect the rest of the plant at all. The DMRP philosophy allows the cell manager to reschedule or acquire extra capacity as long as the delivery dates of previously firmed orders are not compromised. However, if an unforeseen event is likely to affect the scheduled orders for other cells, the feedback mechanism is used to inform the customer cell of any delays, so that the customer cell could reschedule the cells operations in a way which least compromises the total production plan.

The calculation of requirements cascades from the top level cells, which perform final assembly, through intermediate assembly to those concerned with component manufacturing and purchasing. When a feedback message is received, the MRP II system is utilised to assess the impact of any changes and generate revised order actions which are fed down the system in the manner described earlier.

Figure (8.2), highlights the basic feedback and order release mechanism of DMRP methodology. A unique enhancement to the existing MRP II systems and the centralised OPT software is the fact

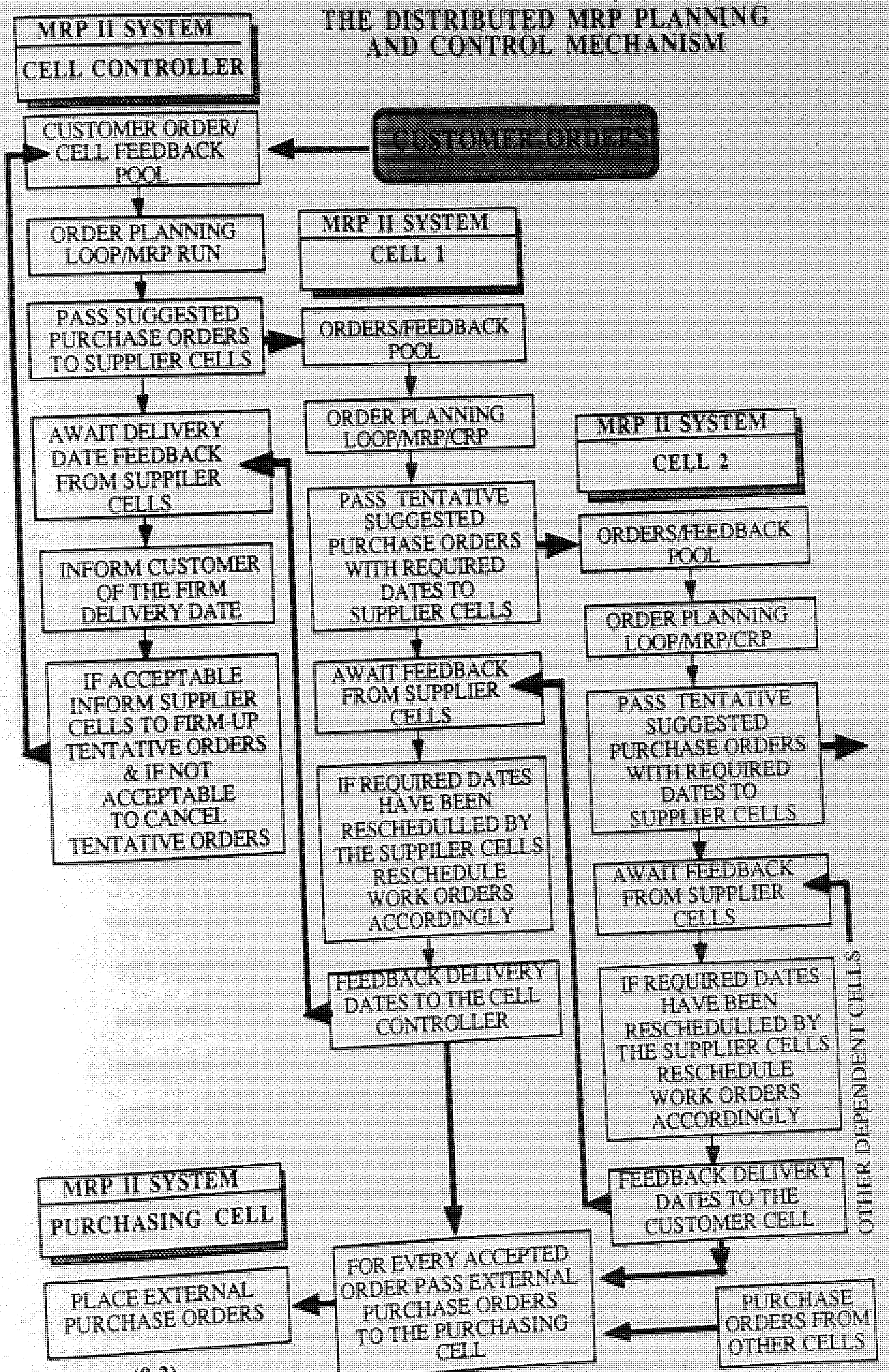

THE DISTRIBUTED MRP PLANNING AND CONTROL MECHANISM
MRP II SYSTEM
CELL CONTROLLER
CUSTOMER ORDERS
CUSTOMER ORDER/ CELL FEEDBACK POOL
ORDER PLANNING LOOP/MRP RUN
PASS SUGGESTED PURCHASE ORDERS TO SUPPLIER CELLS
AWAIT DELIVERY DATE FEEDBACK FROM SUPPILER CELLS
INFORM CUSTOMER OF THE FIRM DELIVERY DATE
IF ACCEPTABLE INFORM SUPPLIER CELLS TO FIRM-UP TENTATIVE ORDERS & IF NOT ACCEPTABLE TO CANCEL TENTATIVE ORDERS
MRP II SYSTEM
CELL 1
ORDERS/FEEDBACK POOL
ORDER PLANNING LOOP/MRP/CRP
PASS TENTATIVE SUGGESTED PURCHASE ORDERS WITH REQUIRED DATES TO SUPPLIER CELLS
AWAIT FEEDBACK FROM SUPPLIER CELLS
IF REQUIRED DATES HAVE BEEN RESCHEDULLED BY THE SUPPILER CELLS RESCHEDULE WORK ORDERS ACCORDINGLY
FEEDBACK DELIVERY DATES TO THE CELL CONTROLLER
MRP II SYSTEM
CELL 2
ORDERS/FEEDBACK POOL
ORDER PLANNING LOOP/MRP/CRP
PASS TENTATIVE SUGGESTED PURCHASE ORDERS WITH REQUIRED DATES TO SUPPLIER CELLS
AWAIT FEEDBACK FROM SUPPLIER CELLS
IF REQUIRED DATES HAVE BEEN RESCHEDULLED BY THE SUPPLIER CELLS RESCHEDULE WORK ORDERS ACCORDINGLY
FEEDBACK DELIVERY DATES TO THE CUSTOMER CELL
OTHER DEPENDENT CELLS
MRP II SYSTEM
PURCHASING CELL
PLACE EXTERNAL PURCHASE ORDERS
FOR EVERY ACCEPTED ORDER PASS EXTERNAL PURCHASE ORDERS TO THE PURCHASING CELL
PURCHASE ORDERS FROM OTHER CELLS

Figure (8.2)

that the position of the bottleneck is not predetermined and that the system copes equally well with transient and permanent bottlenecks. This methodology can be described as an example of 'bottom-up ' planning and control, since its response is driven by the local cell conditions.

The configuration of the local system can be adjusted to reflect the needs of the cell, for example work in progress tracking, scheduling and capacity analysis systems are likely to vary between cells in the same factory. The independence of the individual cell systems, permits local management to replan their activities as and when required. Local policies and procedures, such as JIT manufacturing, stocking and batching rules, may be implemented without the need to extensively update other parts of the system . The accountability for such actions would be clear as would appropriate measures of cell business performance.

Distributing the control system across the computers located in each of the manufacturing cells means that each computer has to deal only with the inventory items associated with the product family within each cell. The local computer can therefore offer improved response times and greater flexibility than an equivalent centralised system. This is an essential prerequisite to provide cell management with the means to perform extensive 'what if' analysis during the generation of the production programme.

The simplicity of the cell 'product' bills of material together with extensive local knowledge also ensures that a clear linkage exists between MPS entries and workcentre loads. The discussions above clearly suggest that DMRP methodology, negates the major shortcomings of the existing production planning and control systems.

8.3 DMRP AS A TOOL FOR MANUFACTURING SYSTEMS INTEGRATION

One of the important features of the DMRP system is the flexibility it would bring into the manufacturing environment for systematic production technology changes. The cellular plant layout and organisational structure allows for a great deal of flexibility in simplifying the production control task. DMRP system resolves the problems associated with integration of various production processes thus facilitating the use of a diverse range of cells. These could include simple cells operating on simple Kanban production control for high volume repetitive products to FMS based advanced manufacturing technology for other groups of products.

The system requires the basic schedule of delivery from each of the dependent cells; the manufacturing techniques utilised in each cell therefore, are of no relevance in the derivation of the plant-wide schedules. A plant could implement a focused manufacturing cell producing a complete range of products alongside functional cells.

8.4 CONCLUDING REMARKS

The discussion above provided an overview of the DMRP methodology. The concept clearly negated the the disadvantages of the existing centralised production planning and control systems.

The capacity sensitivity and flexibility of the DMRP system, was further investigated utilising the prototype system. The system's performance had to be compared against the existing centralised MRP II system. The next chapter will discuss the verification procedures which were undertaken.

CHAPTER 9 VERIFICATION AND DESIGN OF THE DMRP SYSTEM

To evaluate the behaviour of DMRP methodology, it was necessary to develop a prototype system. The system could then be operated under simulated cellular plant conditions. This would firstly allow the basic principle to be verified and could then be used to experiment with various operational scenarios to establish a practical DMRP methodology. Secondly, the optimal methodology could then be compared for its performance, against the conventional MRP approach, using a computer simulated factory model.

9.1 CRITERIA FOR SELECTING AN MRP II SYSTEM

To develop the DMRP prototype, the following criteria had to be met:

- Must be micro computer based;
- Must be commercially available;
- Must be user friendly and modular;
- Must have capacity planning tools;
- Must work on a local area network and be easy to modify;
- Must be inexpensive;
- Must have help line and user support services;
- Must be upgraded regularly by the supplier to exploit new developments in computer technology.

There were a number of micro based MRP II systems which satisfied the majority of the criteria stated above, however, Sheffield Computer Group, offered substantial discount on their UNIPLAN II MRP II system. As a result, the UNIPLAN software was evaluated and proved suitable for the development of the prototype DMRP system.

UNIPLAN is a multi user micro computer based MRP II system, consisting of the following modules:

PARTPLAN;	material control and order processing
JOBPLAN;	estimating and cost control
LEDGERPLAN;	accounting ledger with payroll
INFOPLAN;	report writer

The system is menu driven. The user is presented with a series of menus which lead from the general to the particular, as well as the option to go directly to any option. The MRP module is regenerative. Further details of the facilities in UNIPLAN including the main menu screens are included in appendix (I).

9.2 OVERVIEW OF THE COMPUTER NETWORK

The distributed MRP philosophy, as was described in preceding chapter, is based on a cellular plant layout and organisational principles. DMRP methodology relies on the cell by cell planning of production, by the cell managers. It was therefore, necessary to distribute MRP II systems across a number of notional manufacturing cells. This was achieved through the use of an Apricot Local Area Network hosted by an Apricot master fileserver, connected to a series of IBM AT compatible micro computers, each with their own local data storage facilities. The simulated Factory layout in these experiments were constructed utilising six independent manufacturing cells. These cell based MRP II systems contained all the relevant manufacturing data relating to the products or components that they were responsible for. Therefore, they could execute MRP runs, as well as other MRP II modules, such as Capacity Requirements Planning (CRP) or Work in Progress (WIP) tracking, independently of other cells. The network also facilitated the transfer of data between the cells. The feedback mechanism at this stage of development however, was manual (ie, paper print outs).

9.3 OVERVIEW OF THE DMRP VERIFICATION PROCEDURE

Having installed the above system configuration, the verification of the DMRP methodology was executed in three stages. The first stage was to test that for a range of manufacturing data, the cascade process of DMRP system would in practice result in exactly the same output as that from a centralised MRP II system.

The second stage was a more extensive set of experiments and analysis to investigate the following:

(1) to investigate DMRP operating methodology when applied to practical industrial environments;
(2) to investigate the practical implications of operating a plant utilising DMRP methodology;
(3) to investigate the broader implications of implementing a DMRP

system in manufacturing company;

(4) to suggest how the system could be further developed and to identify the scope for further development.

The third stage was a computer simulation study, based on a series of experiments over 48 weekly periods of operation. The comparison was carried out with exactly the same data and starting conditions, between a computer simulation model of a factory utilising a centralised MRP II system, with weekly MRP runs without any form of capacity planning and the same factory operating under the DMRP methodology. The former procedure is the most common mode of operation in industry, including 'BT Fulcrum Plc', the main sponsors of the research. As it was stated in the preceding discussions, this mode of operation is imposed on most companies, due to the lengthy data processing requirements (up to 8 hours in BT Fulcrum Plc.) and the fact that database access has to cease, during the period when a regenerative MRP run takes place.

9.3.1 VERIFICATION OF DMRP PRINCIPLE

To establish the integrity of DMRP methodology, a simulated factory model consisting of six manufacturing cells and controlled by a conventional MRP II system was configured.

The range of BOMs were designed to include many permutations of levels and manufacturing routings varied from very simple one cell one operations to multi cell, multi operations. Both DMRP and the conventional MRP II system were then set up with the same basic lead time and inventory status data. The MRP run was then executed. The results of the MRP run for both the suggested purchased and manufactured parts along with their corresponding start and due date information were compared to the results obtained from a DMRP system. Over a range of demand conditions, when operating the two systems with fixed lead time data, the two systems were shown to have identical output.

Having established the integrity of the distributed data principle, the flexibility of the DMRP approach and the potential advantages of the above system configuration could be investigated.

9.4 INVESTIGATION OF ISSUES RELATING TO THE OPERATION OF DMRP METHODOLOGY IN INDUSTRIAL ENVIRONMENTS

Clearly the development of the DMRP philosophy, was initiated to provide an improved production planning and control system, which would yield significant operational performance improvements over conventional MRP II systems. These included reduced lead times, capacity sensitive planning, bottleneck identification (both transient and fixed), reduced WIP and improved due data performance. The establishment of the advantages of the DMRP methodology over the conventional MRP methodology, was preceded with the determination of a feasible distributed operating methodology. The following discussions will demonstrate the basic operational methodology of the DMRP system, based on the practical experience gained from the operational experiments which were initiated.

These experiments were based on a sample of manufacturing data from BT Fulcrum Plc., the main sponsors of the research program. Again a series of BOM and routing files were created to provide a diversity of BOM levels and production dependencies, as well as, routings with a wide range of set-up and unit production times, to create occasional temporary bottlenecks on various production cells.

The above data configuration was specifically included to investigate the DMRP's performance in dealing with transient bottlenecks (or capacity constraints), which were a feature of BT Fulcrum Plc.'s manufacturing operations.

The resultant operational methodology and the introduction of new terminology (which will be explained in the following discussions), were as a direct result of the above experiments. The procedures and all the decision making processes, followed the full planning cycle of the DMRP methodology.

This phase of the verification procedure resulted in the fine tuning of the whole concept. The need for pooling of customer orders to allow sufficient time for the cell managers to carry out their respective planning and decision making functions, was also identified as a result of the above experiments.

A further practical finding of these experiments was in demonstrating the importance of the appropriate level of computer data processing resources which would be required to reduce the MRP run execution time to allow for frequent cell based 'what if analysis'. The exact methodology of the dynamic scheduling based on priority and available transient capacity conditions on the shop floor, would vary in detail depending on the facilities available on an MRP II system and the ease with which they could be operated. The environmental factors of a particular manufacturing company would also play an important role in determining an optimal planning procedure. For example, if a company receives on average two orders a day manual scheduling and CRP analysis might be adequate and conversely, if many orders are received for a wide range of products, then the cell based MRP II system in conjunction with any specialist additional planning tools would need to be fully utilised to carry out the major part of the DMRP planning methodology. The full planning methodology providing details of the specific UNIPLAN menu options utilised, have been included in Appendix (II).

In a company where the cells have been organised on a product family basis, with a cell manufacturing the complete product, the cell manager might find that a planning board indicating the current planned works orders and a simple precalculated table of technological lead times against a range of batch quantities of a given product, would allow him to give a tentative production start and finish dates to an enquiry, without using the full range of MRP II system's facilities. The flexibility of the DMRP methodology allows for shopfloor initiative without creating an informal and disorganised method of planning.

In another manufacturing environment, if dependency between cells exists, the same simple planning aids could lead to the determination of start and finish dates for the manufacturing activity in a cell; in which case, the start and due dates for a work order could be entered into the MRP II system and upon execution of an MRP run, the suggested purchase orders be passed on to the dependent supplier cell, (or cells), without utilising the available CRP module of the MRP II or any other additional finite scheduling tool. The integrity of a schedule is still maintained since the dependent cells are responsible for the derivation of their production schedules based on the stated company policy and the particular cell based conditions.

The above examples demonstrate that the DMRP methodology is flexible enough to be accepted on the shop floor as a practical bottom-up planning tool, and not a rigid top management imposed discipline. Therefore, it was concluded that the DMRP methodology allows for the planning and scheduling of the works orders, step by step, based on the local cell conditions.

The additional feedback facility referred to earlier, further enhances the planning methodology, by allowing for rescheduling of work orders, if one or more dependent cells (based on existing production commitments or production problems etc.), cannot meet the required delivery dates requested by a preceding customer cell. This feedback facility, it is suggested, is a closed loop solution that centralised MRP II systems often lack. Shopfloor decision making ensures that the total DMRP system is always in step with the dynamic nature of the plant. Every DMRP planning loop updates the total system of any important changes in the plant status.

Another departure from the conventional MRP II planning methodology, is the introduction of the 'tentative planning loop'. The above term refers to the fact that all the schedules in the dependent cells are considered tentative, until all the rescheduling and feed back activities have taken place (ie, when the last cell in the production route has signalled that it can meet the required due date of any order received from other cells). Only when a feasible production schedule has been obtained, the resultant work order schedules are converted to 'firm' work order status. In practical terms, in order to allow for planning and decision making time, customer orders would need to be pooled into specific time buckets.

The pooling of customer orders and frequent execution of the MRP runs, is also a unique feature of the DMRP methodology when utilising a regenerative MRP/MRP II system. Clearly, with a net change system this approach might not be necessary, since MRP runs would not take a long time and therefore, orders could be planned as they arrive. In conventional MRP II environments, operating a 'make to order' policy, the due date for a customer order is based on the average lead times of the components of a product. This compromise is necessary to compensate for the capacity insensitiveness of MRP planning methodology, as well as, the lack of timely plant status information upon which schedules could be made.

The DMRP methodology, allows for the determination of a feasible production schedule based on the plant status . This feature allows a company to introduce order priority ranking when orders are pooled, as well as providing a competitive edge over other suppliers, in being able to give realistic, as well as, shorter delivery dates to customer orders.

Another feature of the DMRP planning loop is the ability to tell a customer if capacity exists to deliver the order in separate batches. The splitting, can also be carried out in conventional MRP II environments, however, it is an uncommon practice in industry, since the creation of extra works orders or part numbers would further add to the data processing bottlenecks and would further lengthen the MRP runs.

In a distributed MRP environment the introduction of batch splitting can easily be introduced as a matter of policy, specifically on bottleneck cells if a priority order needs to be manufactured. The distribution of manufacturing data across a number of computers reduces the total planning run, since every order does not have dependencies. Therefore, concurrency of MRP runs could occur, and when they do have dependencies they do not necessarily pass through the same cells.

The viability of the whole decision making processes, results in the ability to determine the best operating procedure for each cell. The cell controller, who is in charge of the total manufacturing operations can introduce policy decisions and monitor their effect by visible means, as well as, computer generated management information data.

The experiments also highlighted the fact that the adoption of Just In Time batch manufacturing, can easily be implemented either for specific cells or for the total plant. DMRP methodology can through its feedback mechanism help establish a Just in Time schedule for each stage of the manufacture of a batch. This is due to the fact that if a dependent cell could manufacture a batch of components well before it actually was need by the customer cell, the cell controller could inform his cell managers not to exceed a certain limit, when producing components earlier than is required.

The establishment of cellular autonomous production cells, has a further global advantage in facilitating the missing link between manufacturing functions and the corporate decision makers (see chapter 2). It is suggested that senior management often view the production planning and control function as being too complicated, and by implication they tend to make important corporate decisions without due regard to their manufacturing capabilities. This approach is potentially damaging to an enterprise in two ways; in some cases the management could believe wrongly that the manufacturing capability or labour skills required for a diversification does not exist, thus missing a market opportunity, or they might commit themselves to the manufacture of products for which technological and labour skills might not be readily available.

The cellular plant layout and the DMRP methodology, provide the basic focused manufacturing cells, with a readily identifiable range of technological resources, as well as, labour skills to allow this missing link to be established. For example, a company wishing to diversify into new product and services could easily tender their tentative product proposals to the cell controller, who in consultation with relevant cell managers, could evaluate their ability to manufacture a new product. This bottom-up approach highlights the ease or difficulty with which corporate objectives could be realised.

9.4.1 COMPARATIVE EVALUATION OF DMRP METHODOLOGY V CAPACITY INSENSITIVE MRP METHODOLOGY

The determination of the basic operational methodology of the DMRP system, was followed by a computer simulation analysis, which attempted to quantitatively assess the operational performance of the DMRP methodology against the conventional capacity insensitive MRP methodology, adopted by manufacturing companies who have implemented an MRP II system. An important further consideration in these experiments, was to demonstrate to BT Fulcrum Plc, the potential advantages of the DMRP methodology, against their existing weekly MRP run production planning methodology, prior to a more detailed study of the issues specifically relating to their medium to long term manufacturing operations.

At the outset, it was decided that a deterministic factory simulation model be developed which would attempt to highlight some of the implications of running a company with the two methodologies, on a 'make to order', just in time manufacturing (ie, based on the suggested work order release dates of conventional MRP and the DMRP methodologies). The advantage of using a deterministic simulation model in these experiments, was in simplifying the comparative analysis of the two methodologies. The use of stochastic elements in the factory model would have obfuscated the simplicity of DMRP methodology without adding any potential benefit at this stage of the development. It was decided that the relative differences between the two approaches could adequately be highlighted with a three product factory consisting of three manufacturing cells. A factory simulator called ATOMS, developed at Aston University, was integrated into the DMRP system through the DESQview quarterdeck software.

9.5 THE SIMULATION MODEL CONFIGURATION

The use of simulation techniques in the design of manufacturing control systems have been discussed in detail in the literature. The following cover most aspects of this process, Love et al (1988b), Love (1980), Love et al (1987) Parnaby (1986), Roggenbuck (1973). The ATOMS simulator was designed to be configurable for any type of manufacturing environment. Love at al (1988b), described in detail the full range of the ATOMS's features. The ATOMS simulator was configured to create a factory model with three work centres with equal capacity. Figure (9.1), is diagrammatical representation of the system configuration . In order to speed up the process of data communication between the ATOMS factory model and the MRP II system, the DESQview software (a proprietary product of Quarterdeck Office Systems) which allows multitasking and easy transfer of data between two separate computer programs, was used as an
interface between UNIPLAN and the ATOMS factory model.

AN OVERVIEW OF THE INTEGRATED CENTRALISED MRP II/SIMULATION MODEL

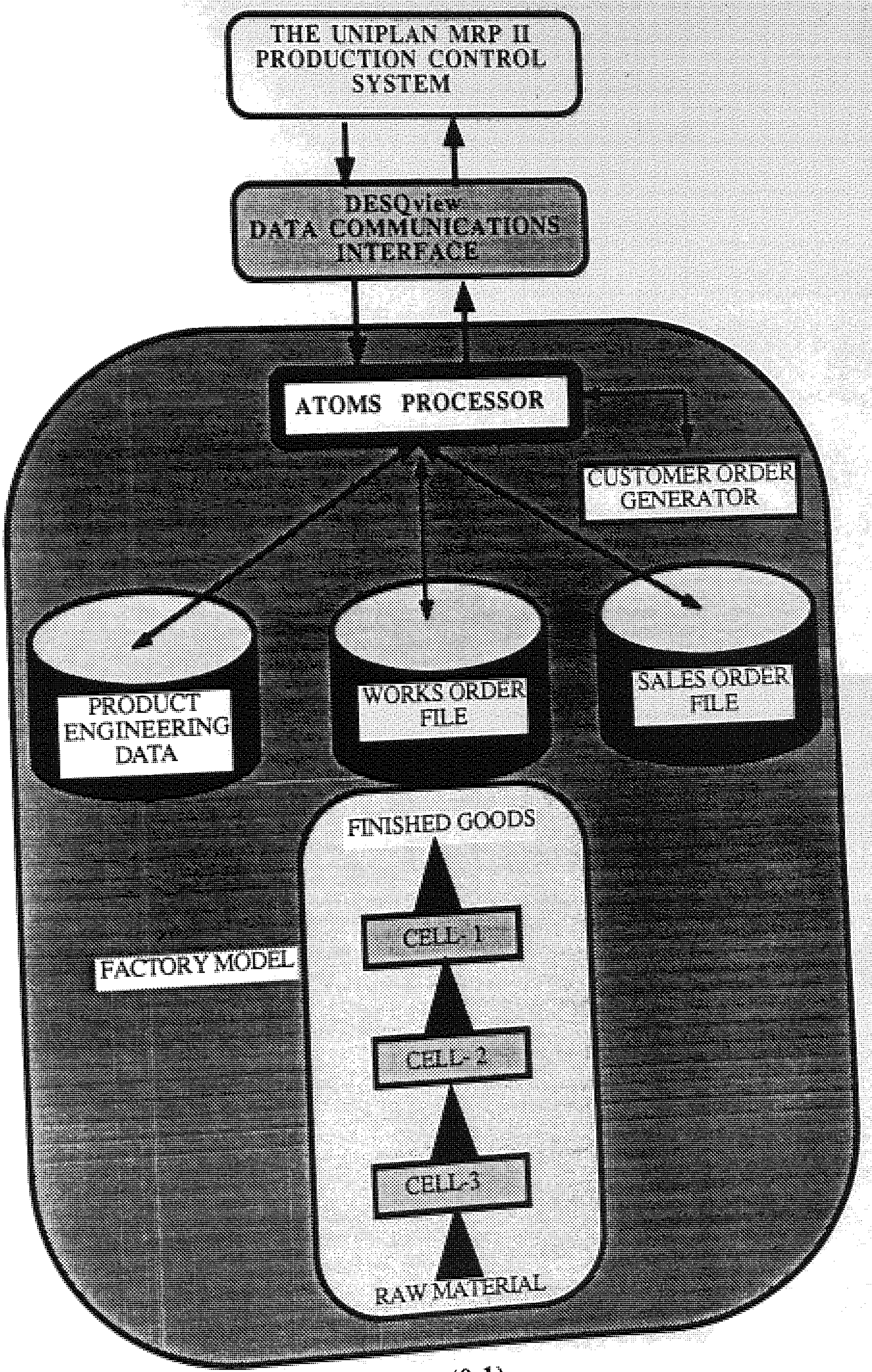


Figure (9.1)

The factory model was set up to manufacture three different MODEMS. Each modem was set up to manufactured from a case and each case from a printed circuit board (PCB). The first three letters of each were used to identify a component and the numbers 100, 200 and 300 represent the three versions of each product. For example, MOD-100 (which is made up of CAS-100 and PCB-100), refers to MODEM model 100.

The products would be manufactured by passing through each of the work centres in whole batch quantities of the customer orders. The production routings data was specifically designed to create temporary bottlenecks in the three manufacturing cells. This was achieved through the specification of fixed set-up time of one hour per operation in each cell. However, the unit production time varied by a factor of three to one for each of the products in consecutive stages of manufacture. Figure (9.2), shows the BOM and the production routing data for the three products.

The customer demand pattern was fixed at a rate of seven orders per five day working week. The arrival days of each customer order were uniformly distributed. Each product had equal probability of being selected and the quantity of each customer order was based on a normal distribution with a mean of thirty and a standard deviation of five. The above attributes resulted in a range of order quantities between fifteen and forty five. The order quantities were rounded to the nearest five to simplify any manual data handing and to reduce as well as identify data input errors. The selection of the mean and standard deviation was as a result of a series of experiments which attempted to find an appropriate rate of demand which on average,

THE MODEL BILL OF MATERIALS & ROUTING DATA

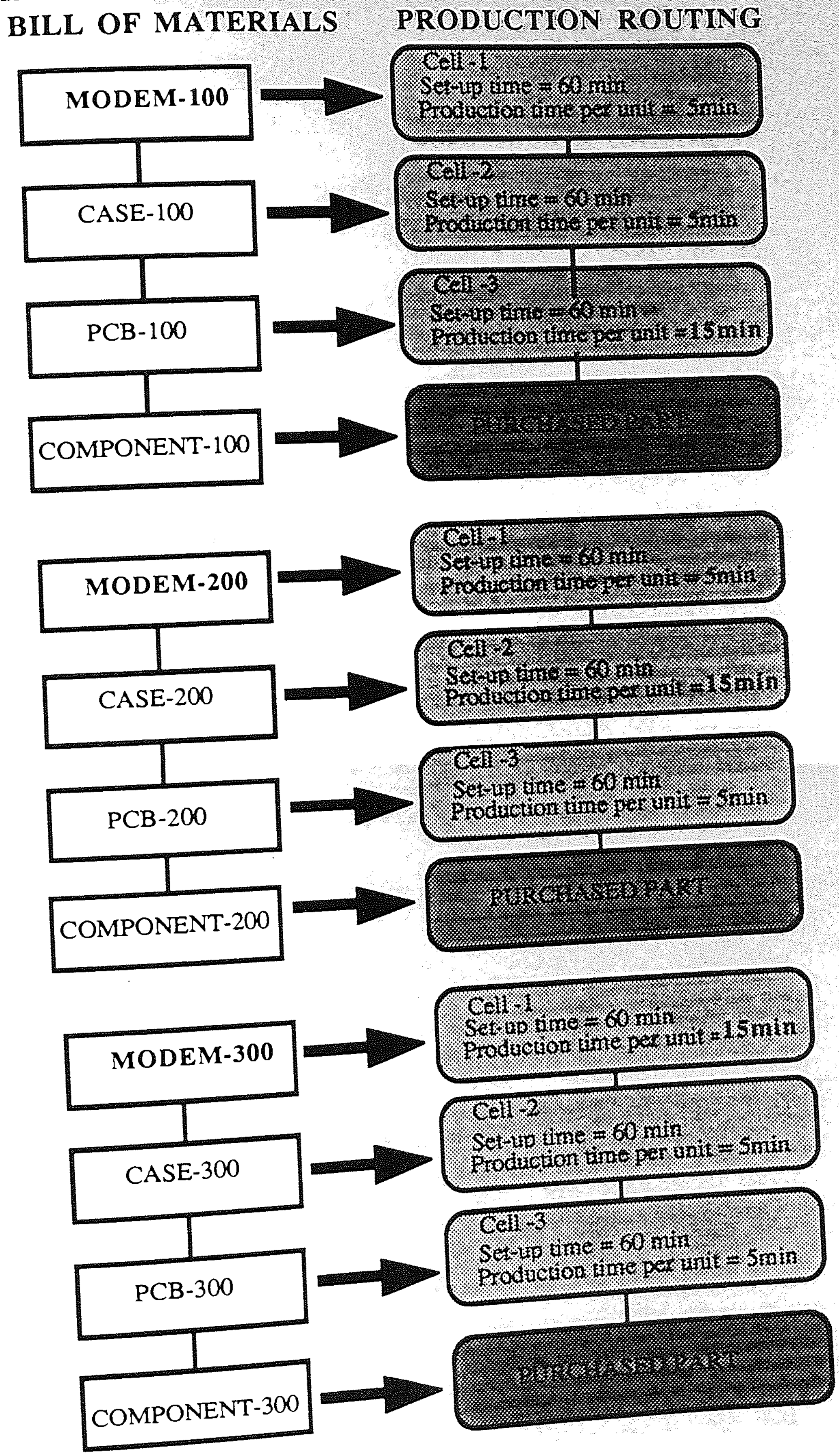


Figure 9.2

would result in a factory loading greater than the total available hours of the three work centres. This approach would ensure that the factory would have some work in progress at the end of some of the periods (as it would be the case in industry). The volatility of customer orders and the subsequent resource constraints were deliberately created to investigate the performance of DMRP methodology against the conventional MRP systems. Appendix (III), includes an overview of the ATOMS system and samples of the model data and the model's output.

9.5.1 DETERMINATION OF AVERAGE LEAD TIMES FOR THE MRP II CONTROL SYSTEM

MRP II systems in industrial environments rely on past performance lead time data to suggest future action plans. In order to implement a conventional MRP II production planning and control system in the factory simulation model, it was necessary to obtain equivalent past performance data. The factory simulation model had to run for a period of time until a steady state condition could be identified. The customer orders which were automatically generated by the ATOMS simulator acted as the initial master production schedule of the factory. The orders were processed in the sequence which they were generated. A large queue of orders had to be processed before a steady state condition was reached. This stage of the experiment was trying to identify the condition where the actual average lead time of the products could be seen to be stabilising around a mean. Clearly the production routing data, capacity availability and the nature of demand affect this condition. To obtain the average lead time data, it was important to run the factory for a sufficient number of periods in order to avoid the large fluctuations in lead times associated with running the model without any work in progress. The data for the end products which were called modems, was collected after fifty weekly periods of production. The data was then analysed to find a suitable starting position from which to collect average lead times data. The steady state condition after which lead time data could be collected was reached after a total of one hundred periods of operations. Figure (9.3), shows the convergence of the average lead times to a steady state condition, after two hundred and twenty weeks. An important additional feature of this graph is the clear effects of the three bottleneck operations which were introduced for each manufacturing cell.

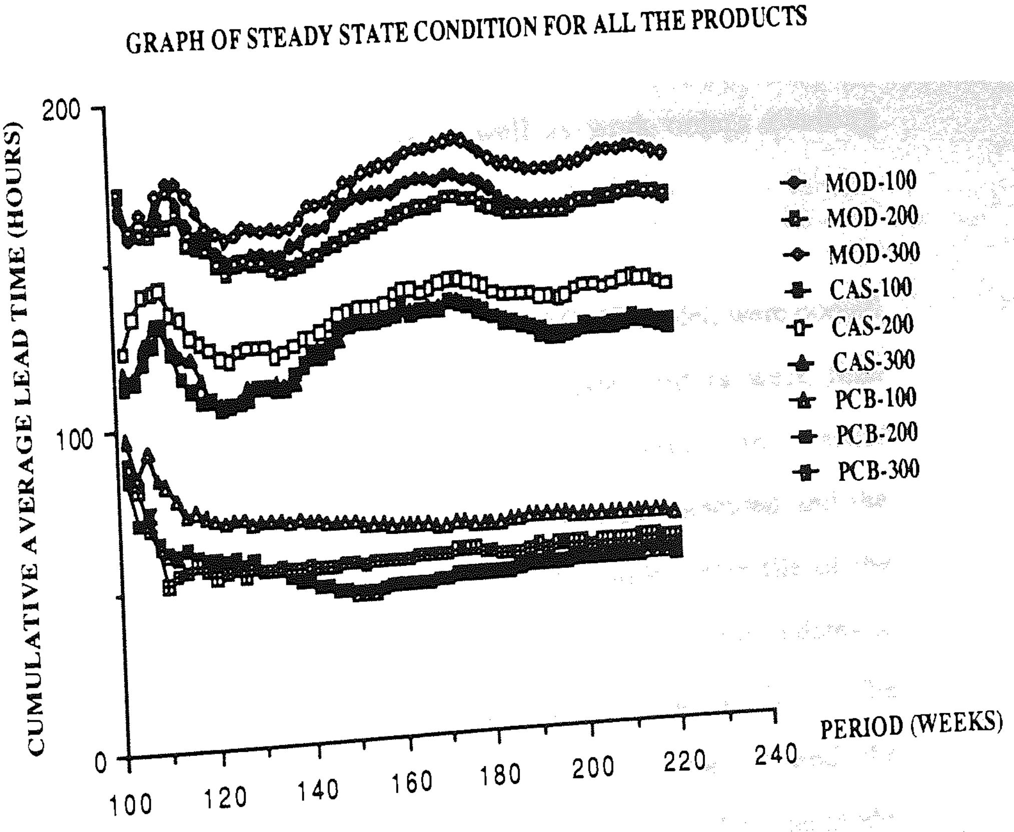

GRAPH OF STEADY STATE CONDITION FOR ALL THE PRODUCTS

Figure (9.3)

From this data the average lead time of the components and the total lead time of each product was estimated to the nearest whole day. This was because the MRP II systems generally work to lead times of days, the UNIPLAN system also plans to the nearest full day. The lead time data along with all the associated production routings information was transferred from the factory model to the MRP II system. This process was equivalent to the implementation of an MRP II system in an industrial environment, though in a much smaller scale. The factory model was then operated for a further forty eight periods, under the control of the UNIPLAN MRP II system, following the industry norm of weekly MRP runs without CRP analysis. CRP is in some companies only utilised to assess overtime requirements and to evaluate the need for sub-contracting excess demand. The starting conditions resembled a realistic industry based implementation of an MRP II system, since there were both work in progress as well as work orders awaiting completion.

The customer orders generated by the ATOMS model, were pooled weekly into a sales order file. The sales orders were then transferred to the UNIPLAN and translated into gross requirements. An MRP run was subsequently executed and the suggested works orders were input to the works order file of the ATOMS factory model via DESQview, the start and finish dates of each works order being scheduled to the nearest full day. The factory model was then executed for each period and the performance of the factory was automatically logged by the model against the customer order file. The performance of the factory over each period was recorded and the results will be discussed in chapter 10 along with the results of the experiment over the same period utilising the DMRP methodology.

9.5.2 INTEGRATION OF THE FACTORY CELL MODELS WITH THE DMRP SYSTEM

In order to evaluate the DMRP methodology, the same factory model with the same steady state starting condition was transformed into three autonomous cells which constituted the centralised model. Figure (9.4), shows an overview of the factory model under DMRP environment. Figure (9.5), shows the basic procedures which were followed at this stage of the experiments.The planning of the work order due dates, was carried out using the DMRP methodology. The major difference between this experiment and the centralised approach discussed in the previous section, was that the plant conditions in each cell were reflected in the production plan. Therefore, the work order file of the ATOMS factory model, was based on the technological lead time per batch and the nearest available day when each work could start and the date that each work order would be expected to have finished.

The results will be discussed in chapter 10. The ATOMS model can handle a work order schedule specified to start and end based on period, day, hour and minutes, (ie, a works order could be scheduled to start at period 5, day 2, hour 10, min 30). However, to ensure the procedure was compatible with using a standard MRP II package, the work orders were scheduled to the nearest day. It was therefore concluded that with an MRP II system which could handle work order start and finish dates in hourly periods, the

AN OVERVIEW OF THE DMRP SIMULATION MODEL

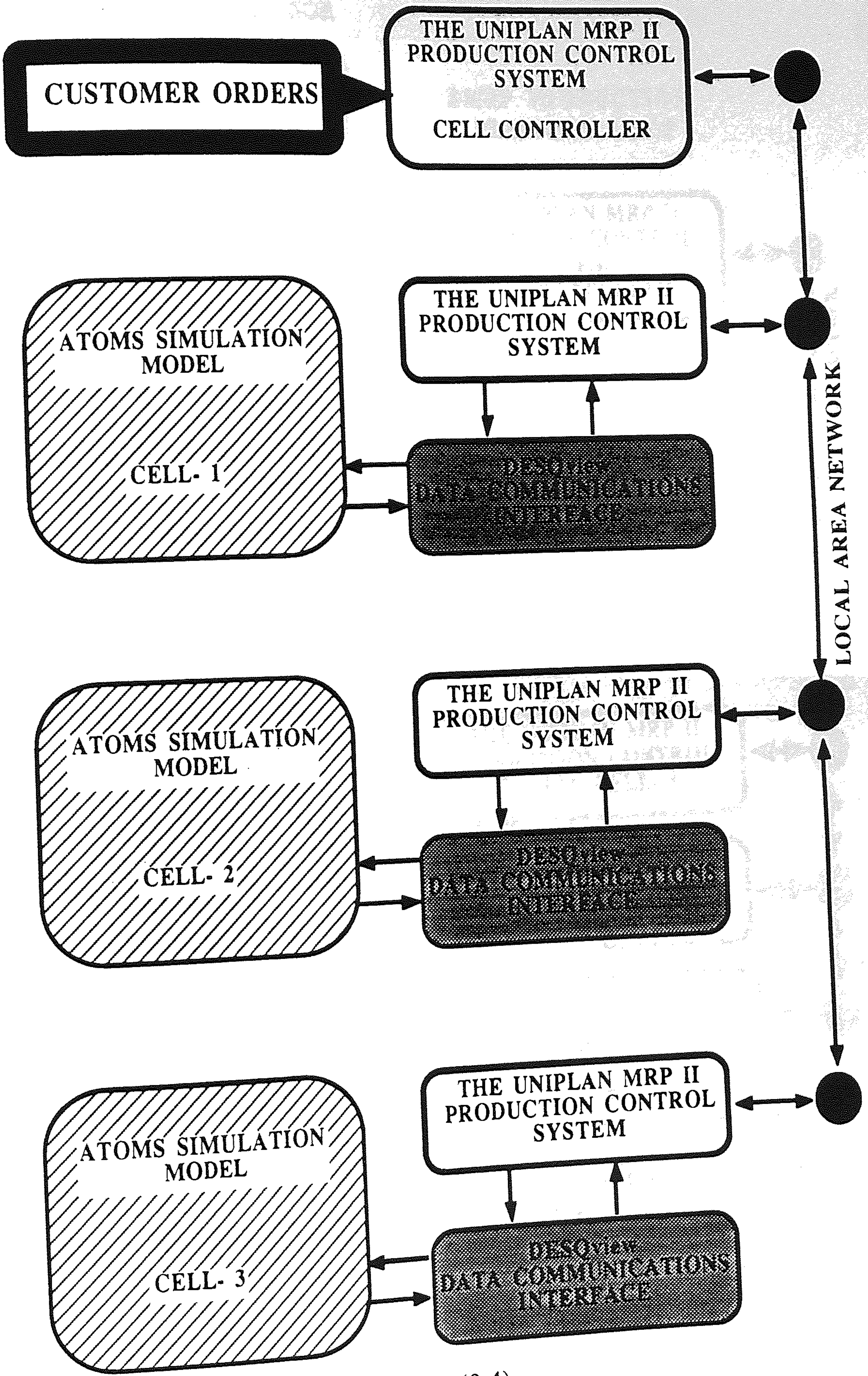


Figure (9.4)

AN OVERIVEW OF DMRP SIMULATION METHODOLOGY

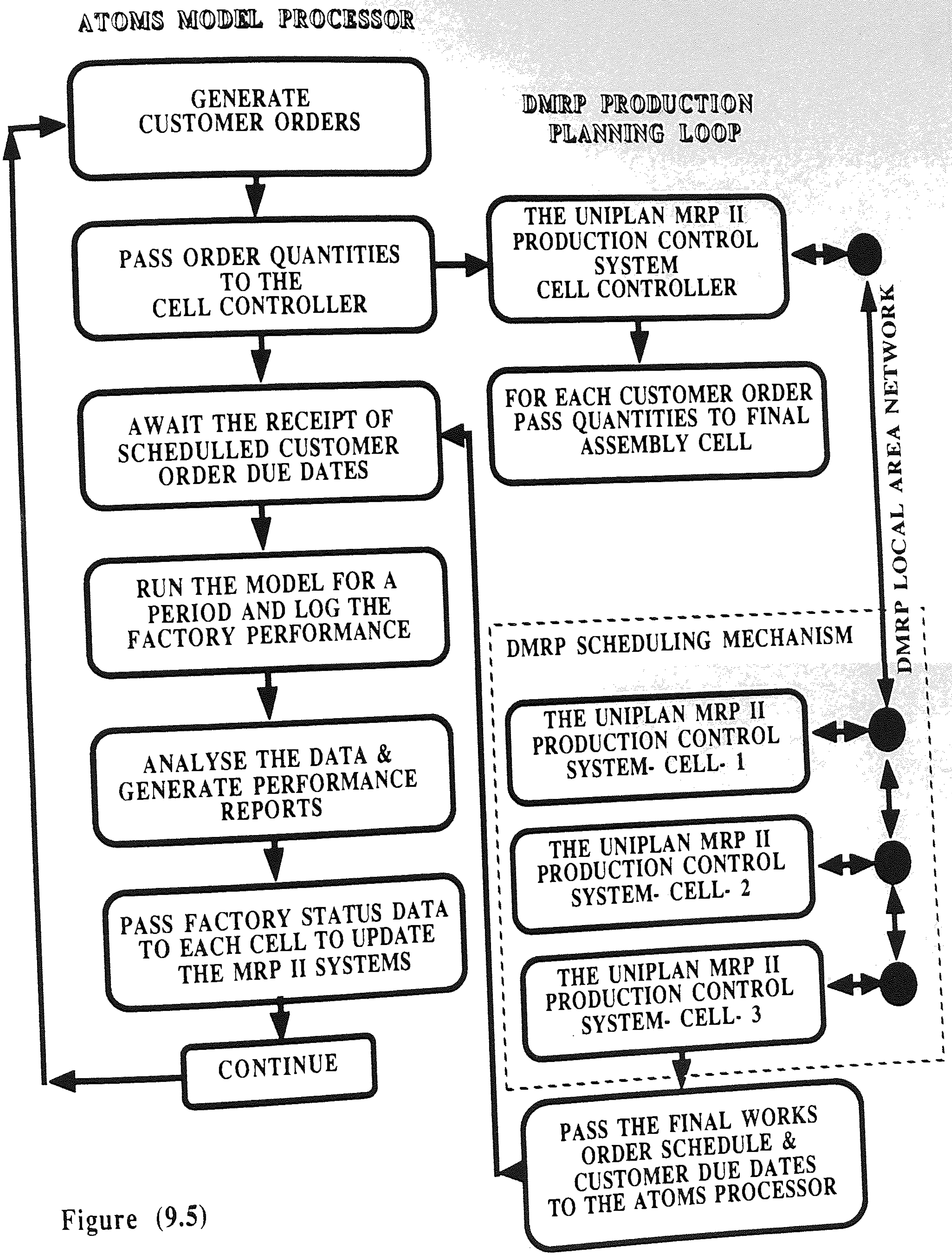


Figure (9.5)

performance of the DMRP methodology with respect to key indicators like, work in progress levels and total manufacturing lead times, would be theoretically more favourable.

9.6 CONCLUDING REMARKS

The results of simulation experiments were then plotted and analysed to provide a quantitative assessment of the DMRP methodology against the way conventional MRP II systems are generally operated in industry. The results of the comparative simulation experiments, will be discussed in the following chapter.

CHAPTER 10 ANALYSIS OF THE RESULTS OF THE SIMULATION EXPERIMENTS

The final stage of the DMRP development, included a comparative investigation of the characteristics of the system. The discussions in chapter 9 established the feasibility of the system. This chapter will discuss the quantitiaive results of the simulation experiments.

10.1 ANALYSIS OF THE RESULTS

The factory simulation models, were identical in every respect, except that the MRP model was operated using the the standard fixed lead time data without any form of capacity planning. Starting from the steady state condition with exactly the same level of work in progress, the two models were executed for a further period of 48 weeks. Exactly the same randomly generated customer orders were used in each case. The stated delivery dates however, were necessarily different, since the use of fixed lead times at every stage of manufacture imposes this mode of operation on companies operating an MRP II system. In a DMRP environment however, this approach is discarded. The orders in this case were pooled in daily time buckets and following the execution of the DMRP planning procedure, each order was scheduled to the nearest whole day based on the transient capacity availability in each dependent cell. The unique feed back loop of the DMRP methodology was therefore exploited to achieve a Just In Time batch production plan. The quantitative performance characteristics which were measured, (ie, lead times, levels of work in progress (WIP), total throughput and delivery performance), will be discussed next.

Figures (10.1), (10.2) and (10.3), show the lead time characteristics of the three types of printed circuit boards, manufactured in cell-3. The manufacture of the PCBs form the first stage of the operations which lead to the delivery of the final three products (Modems).

GRAPH OF PCB-100 LEAD TIME PERFORMANCE UNDER CONVENTIONAL MRP & DMRP ENVIRONMENTS

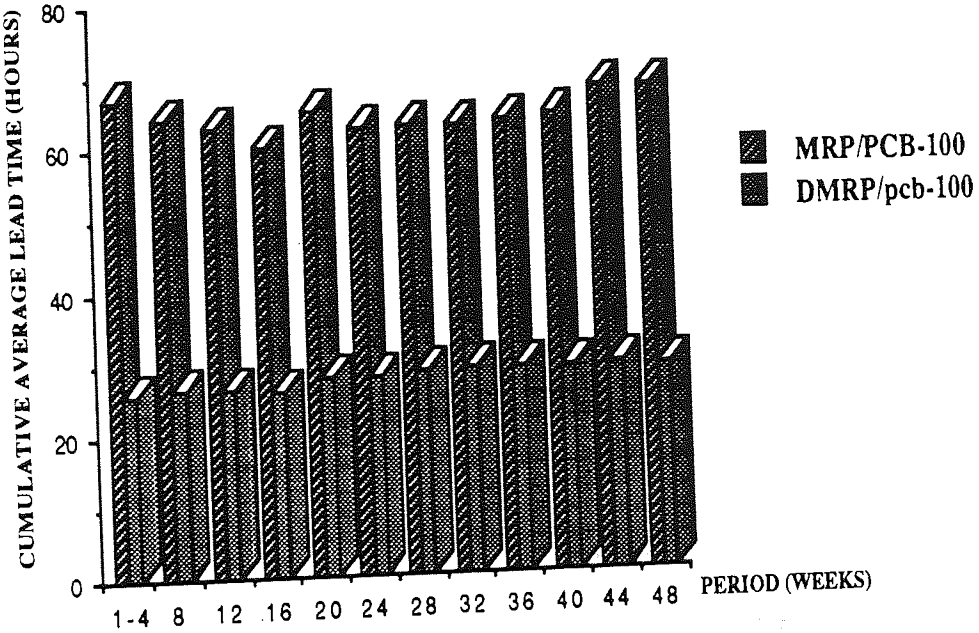


Figure (10.1)

The PCB model 100 Figure (10.1), was set up with the highest work content (3 times the other PCB's) and the resultant larger average lead time compared to PCB models 200 and 300, Figures (10.2 & 10.3) can readily be seen. In the conventional MRP methodology, the use of a larger fixed lead time is considered as the appropriate solution to the problem of ensuring due dates are met on most occasions. The DMRP approach however, considers the technological lead time per batch and schedules the production based on transient capacity conditions.

GRAPH OF PCB-200 LEAD TIME PERFORMANCE UNDER CONVENTIONAL MRP & DMRP ENVIRONMENTS

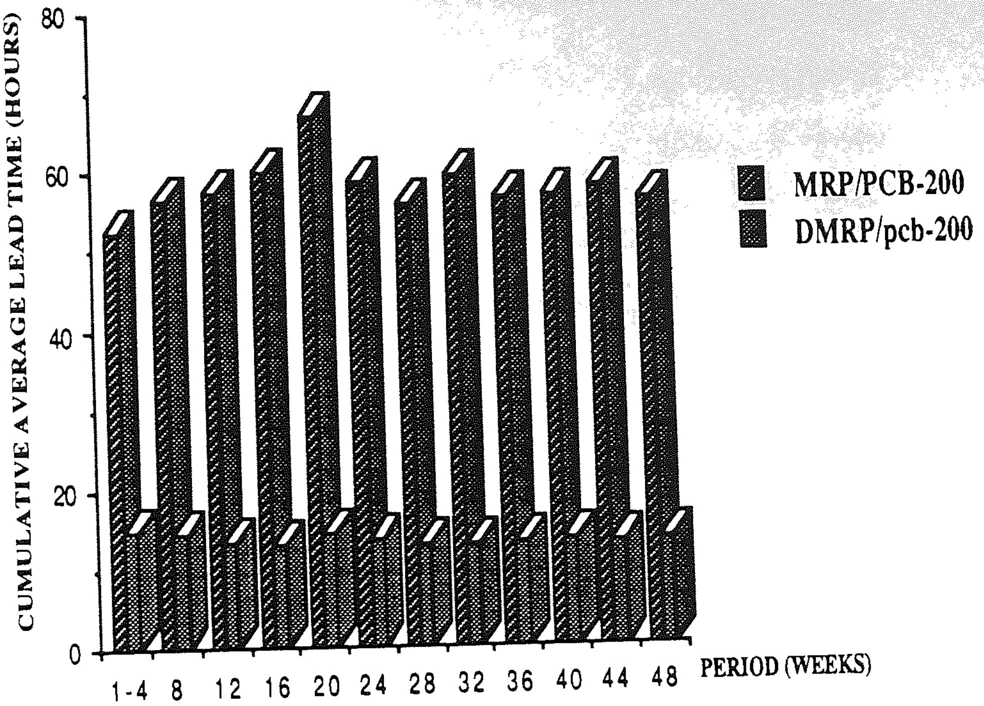


Figure (10.2)

GRAPH OF PCB-300 LEAD TIME PERFORMANCE UNDER CONVENTIONAL MRP & DMRP ENVIRONMENTS

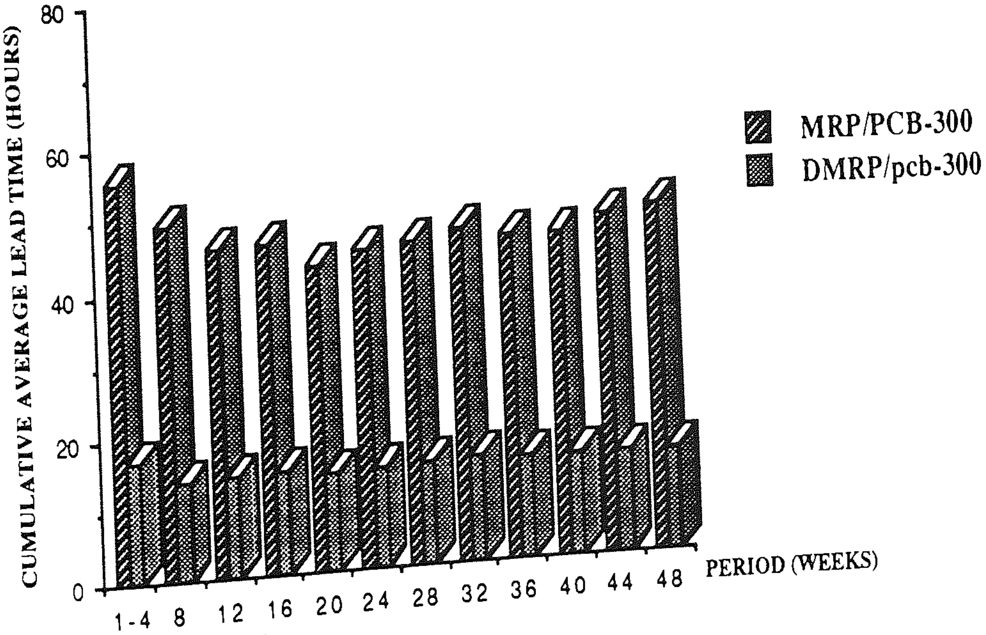


Figure (10.3)

The marked difference between the lead times at the first stage of the manufacturing route, highlights the negative characteristics of the arbitrary use of fixed lead times in conventional MRP/MRP II systems. This simplified example of a manufacturing plant clearly demonstrates the unnecessary loss of throughput and increased manufacturing lead time when applying the MRP methodology in any manufacturing company. Conversely, with the adoption of the cellular plant layout and the exploitation of the local knowledge and independent cell based MRP II system, the same range of products with exactly the same production routings, are manufactured and delivered to the next cell in less than half the fixed average lead time. Furthermore, to ensure that the conventional MRP schedule is adhered to, the general rule in industry, is not to send the finished batches on to the next stage of the manufacturing process, because the next cell, according to the MRP suggested start date will not be expecting the work until its suggested due date. The adherence to the MRP generated schedule therefore, has very grave implications for any business. If the finished orders are passed on to the next stage of the manufacturing operation, the jobs might finish quicker and local WIP levels would be reduced. However, after a while, the integrity of the MRP system will suffer. The adoption of this approach results in the ultimate failure of the MRP implementation. Yet instinctively, the above scenario would be the correct one to adopt.

Figures (10.4), (10.5) and (10.6), show the lead time characteristics of the three type of cases which are manufactured in cell-2.

GRAPH OF CAS-100 LEAD TIME PERFORMANCE UNDER CONVENTIONAL MRP & DMRP ENVIRONMENTS

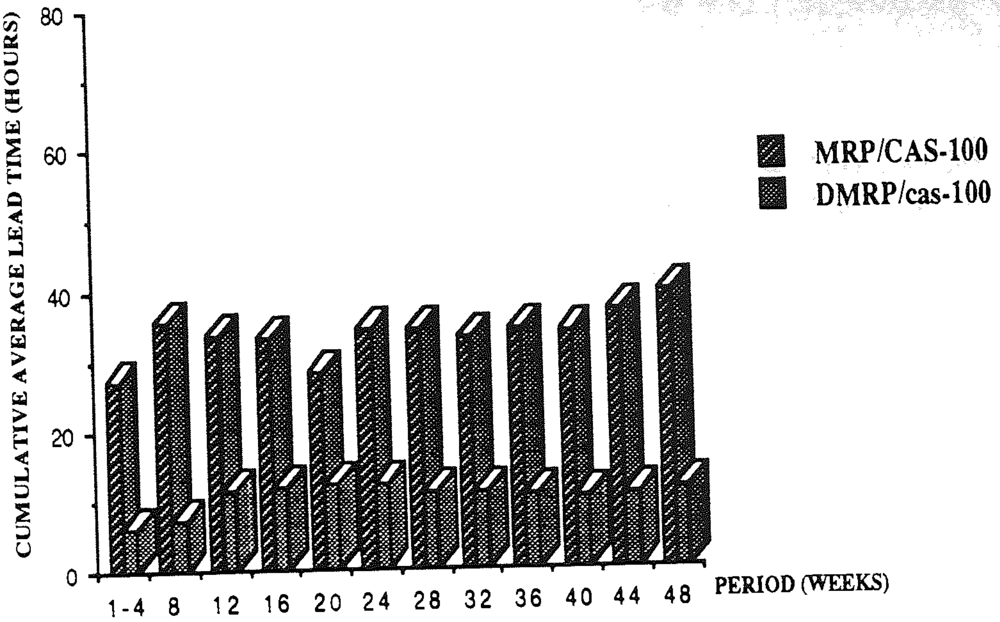


Figure (10.4)

Figure (10.5) , highlights the fact that CAS-200 was set up with the highest work content (3 times the other cases). It is important to recognise the role of bottlenecks in the overall lead time of a product. The capacity sensitive DMRP methodology, can dynamically deal with bottleneck operations as they occur without the need for any additional planning tools. The use of average lead times on bottleneck operations in conventional MRP environments is particularly counter productive when the batch quantities could vary considerably (in this case between 15 to 45). It is suggested that since high utilisation of bottleneck resources is an important factor in achieving high throughput, the use of average lead times is an unsatisfactory tool for planning of manufacturing operations in today's competitive market place.

GRAPH OF CAS-200 LEAD TIME PERFORMANCE UNDER CONVENTIONAL MRP & DMRP ENVIRONMENTS

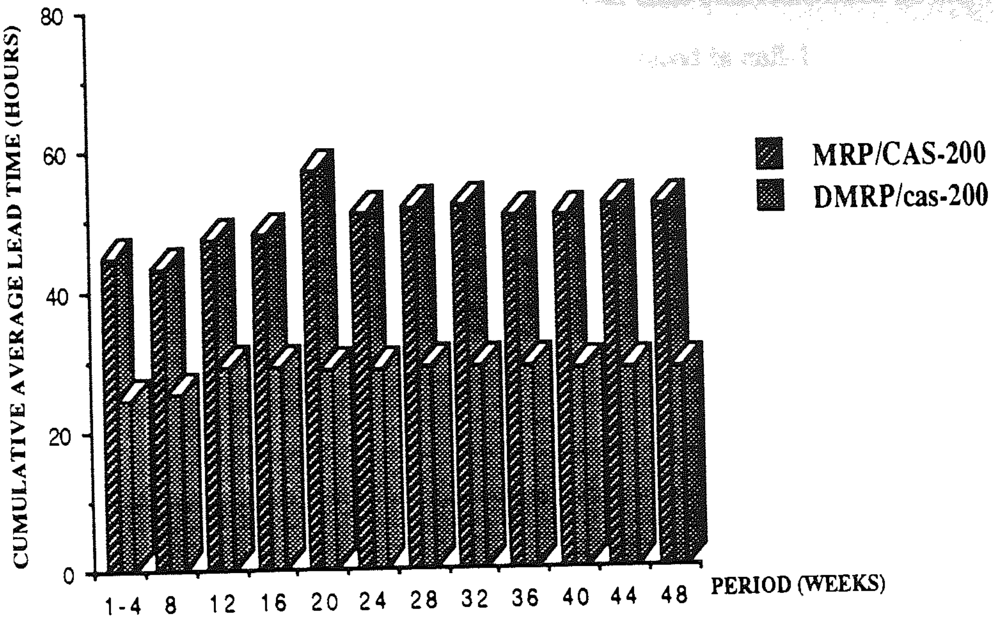


Figure (10.5)

GRAPH OF CAS-300 LEAD TIME PERFORMANCE UNDER CONVENTIONAL MRP & DMRP ENVIRONMENTS

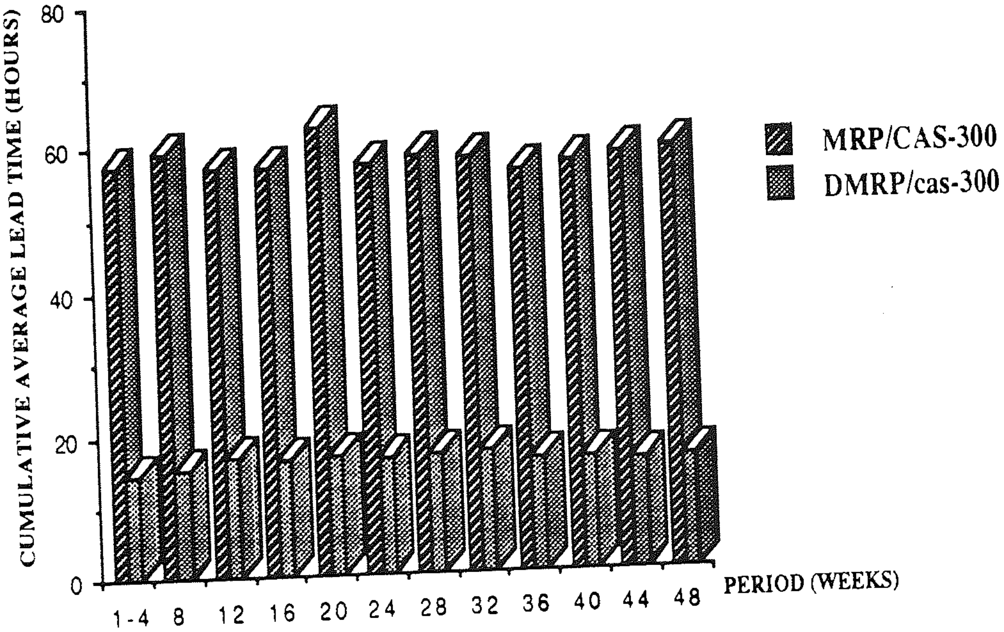


Figure (10.6)

Figures (10.7), (10.8) and (10.9), show the lead time characteristics of the three final assembly products, which are manufactured in cell-1.

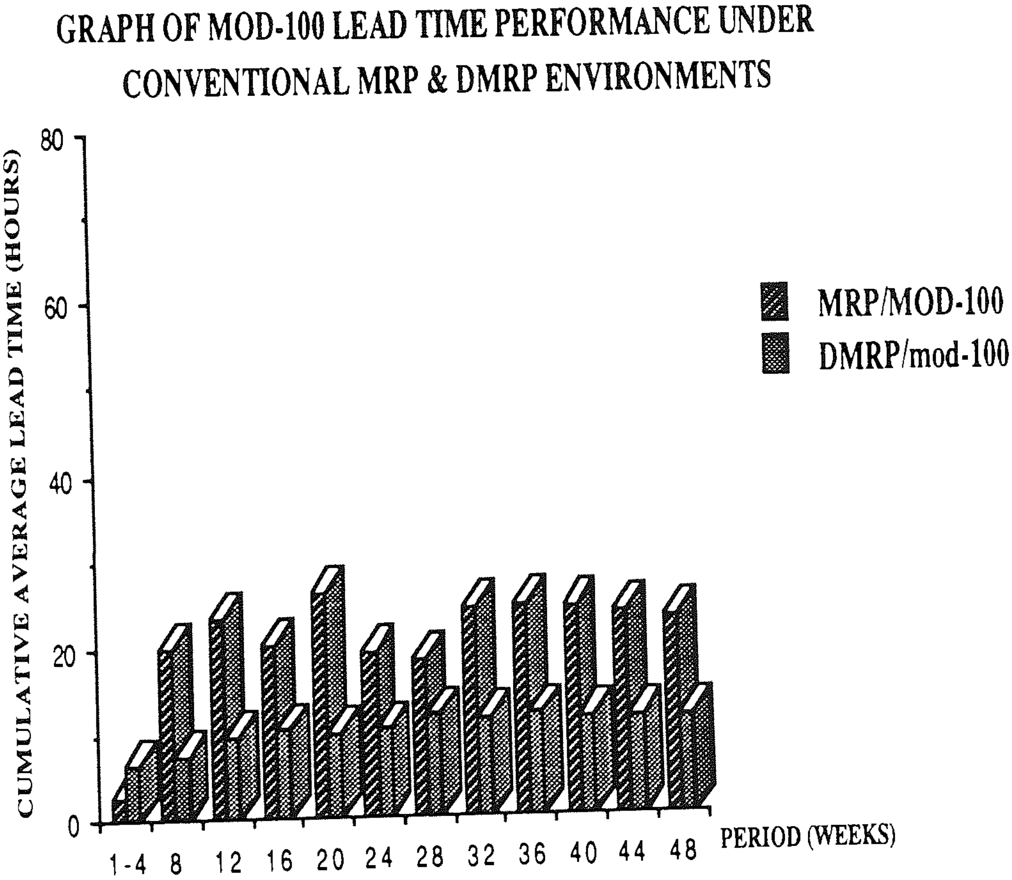


Figure (10.7)

Figure (10.7), shows the greater volatility of lead times in conventional MRP environments. The cumulative effects of having three bottleneck operations in the three manufacturing cells, clearly affect the delivery performance. DMRP, it can be argued, can potentially improve the competitive performance of a manufacturing plant.

GRAPH OF MOD-200 LEAD TIME PERFORMANCE UNDER
CONVENTIONAL MRP & DMRP ENVIRONMENTS

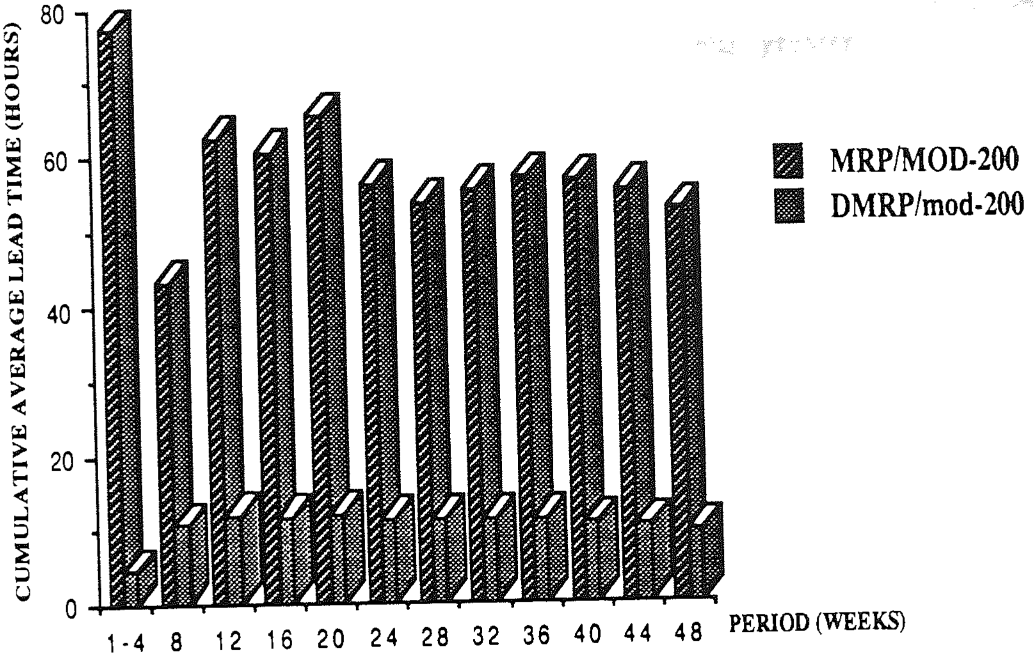


Figure (10.8)

GRAPH OF MOD-300 LEAD TIME PERFORMANCE UNDER
CONVENTIONAL MRP & DMRP ENVIRONMENTS

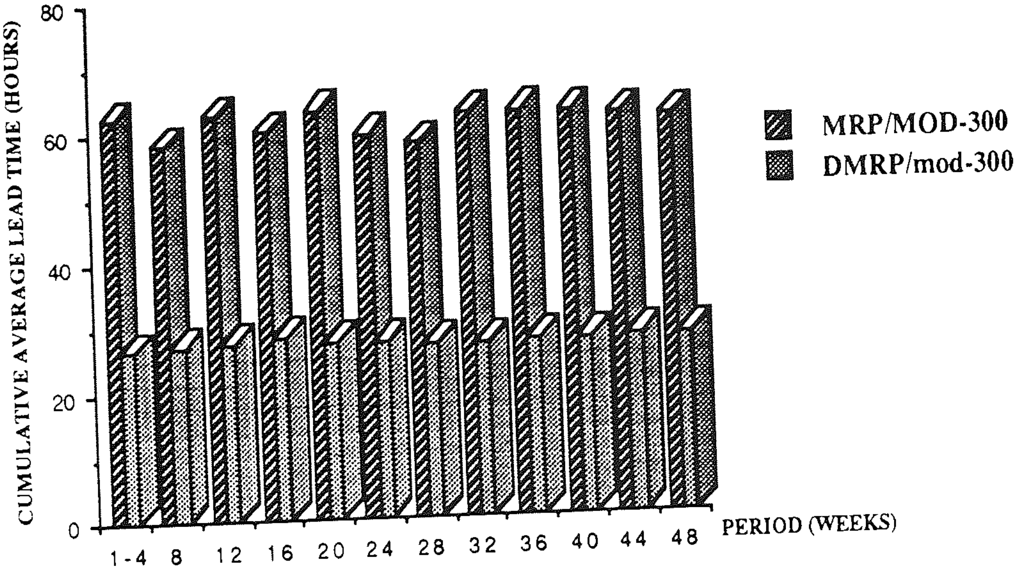


Figure (10.9)

Modem-300, has the highest work content (3 times the other Modems), figure (10.9). Consistent performance is an important tool in maintaining customer satisfaction and thus greater opportunity for business growth.

This relative performance advantage could not however be achieved in a conventional MRP environment because the effects of higher than average demand, would result in late deliveries and subsequent decrease in customer satisfaction.

The consistently lower lead times in DMRP environment are as a direct result of the DMRP methodology. The methodology allows a company to promise delivery dates based on available capacity. Figures (10.10) and (10.11), summarise the lead time performance of the final products under MRP and DMRP environments.

If the plant is overloaded at any one time, the delivery dates would be extended to cover this transient condition. Therefore, any customer order would not be released onto the shopfloor until its planned start date has reached. This in turn would lead to lower manufacturing lead times since the customer has already been informed of the actual delivery date in advance of an order being accepted. Since the manufacturing lead time is a measure of the time an order is released on to the shopfloor and the time it is ready to be dispatched to the customer, the DMRP lead time performance, as a cumulative average would necessarily be much shorter and much less volatile.

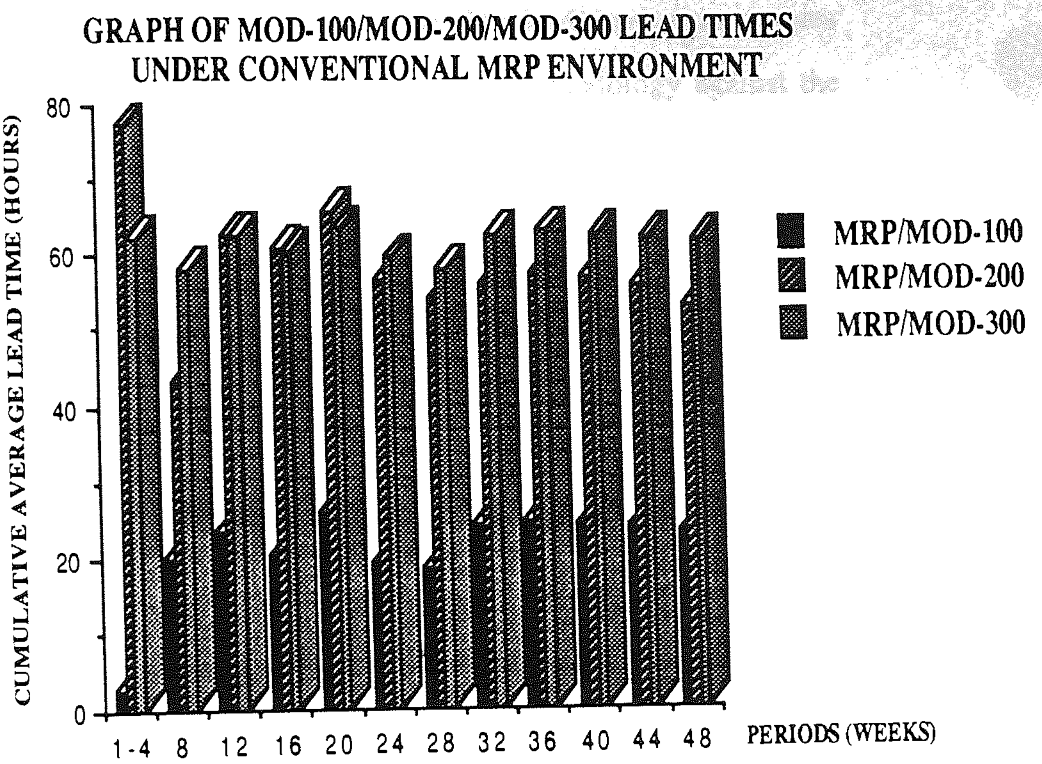


Figure (10.10)

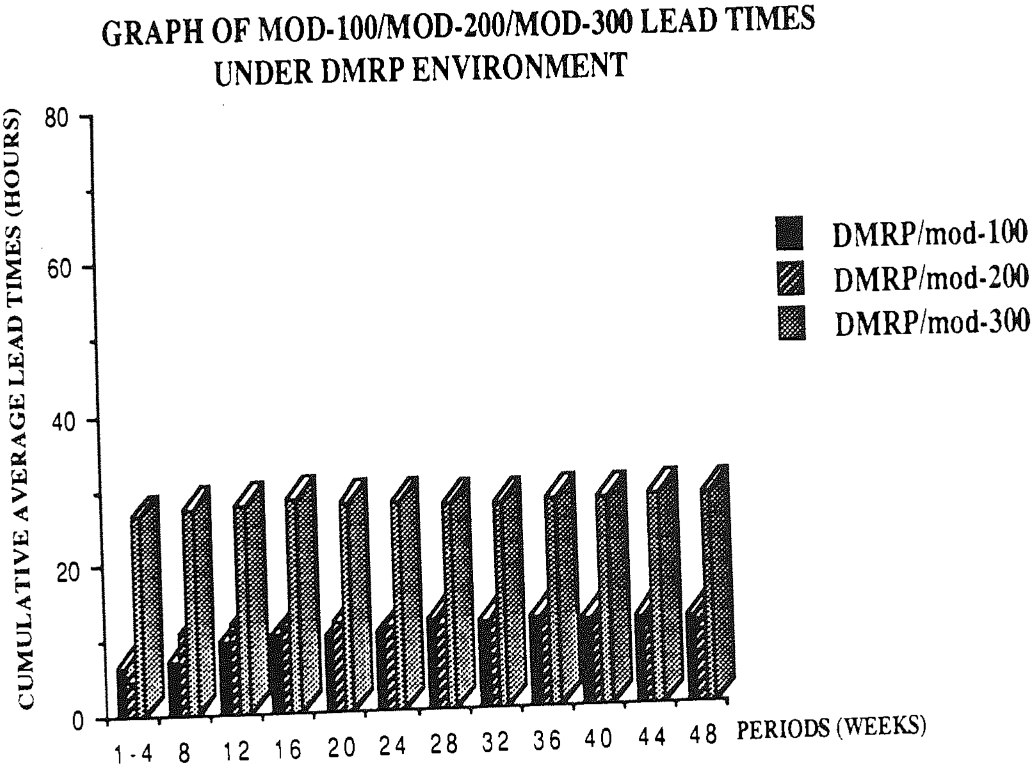


Figure (10.11)

The overall improvements in the product lead times demonstrates the potential advantages of the DMRP methodology against the conventional MRP approach.

One of the most important business efficiency measurements is the number of inventory turnarounds. The discussions in chapter 9 highlighted the Japanese success in reducing their inventory levels in all areas of manufacturing, through the adoption of the Just In Time philosophy. In a conventional MRP system, the centralised planning structure and the capacity insensitivity, mitigates against the achievement of low inventory manufacturing. Such systems as it was stated earlier, when implemented successfully, allow a form of Just In Time manufacturing which utilises past performance as the best guide to current and future performance.

The system users are urged to follow the suggested orders start and due dates so that the system integrity is maintained. Any deviation from the suggested action plan, would soon result in the deterioration and ultimate failure of the MRP system implementation. The Just In Time feature of MRP systems, must be followed to maintain the system integrity. It's effects therefore, on the underlying competitive needs of a business in a dynamic real world environment are potentially damaging.

Figures (10.12) and (10.13), show the work in progress (WIP) levels, sampled at fixed intervals over the 48 weeks of comparative simulation experiments. The high level of WIP at the three manufacturing cells under the MRP environment is as a direct result of the inherently flawed methodology of such systems.

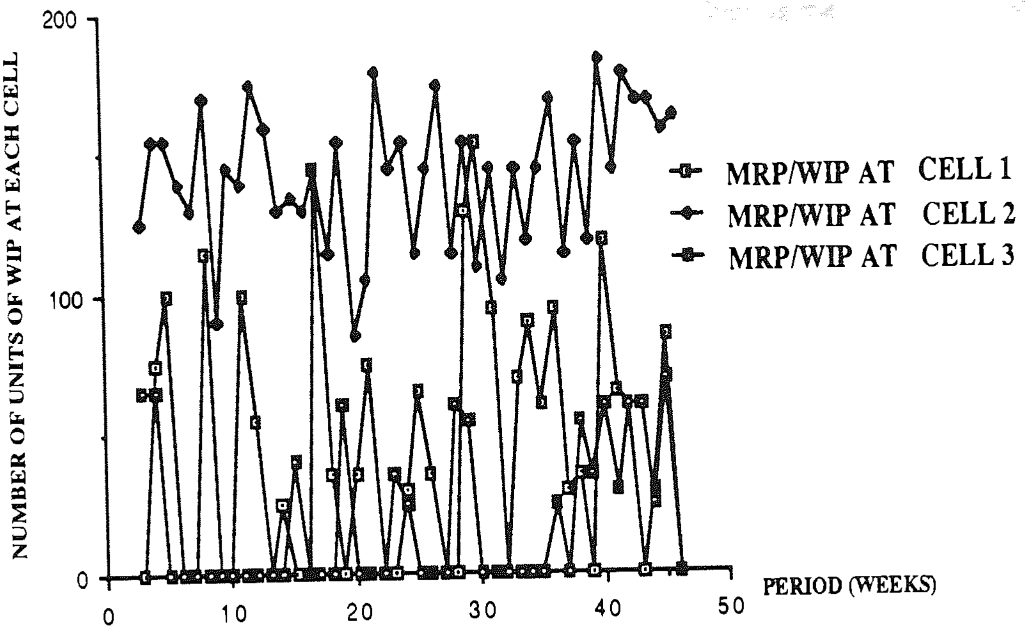

GRAPH OF WIP SAMPLES AT CELLS 1, 2 AND 3
UNDER CONVENTIONAL MRP ENVIRONMENT

Figure (10.12)

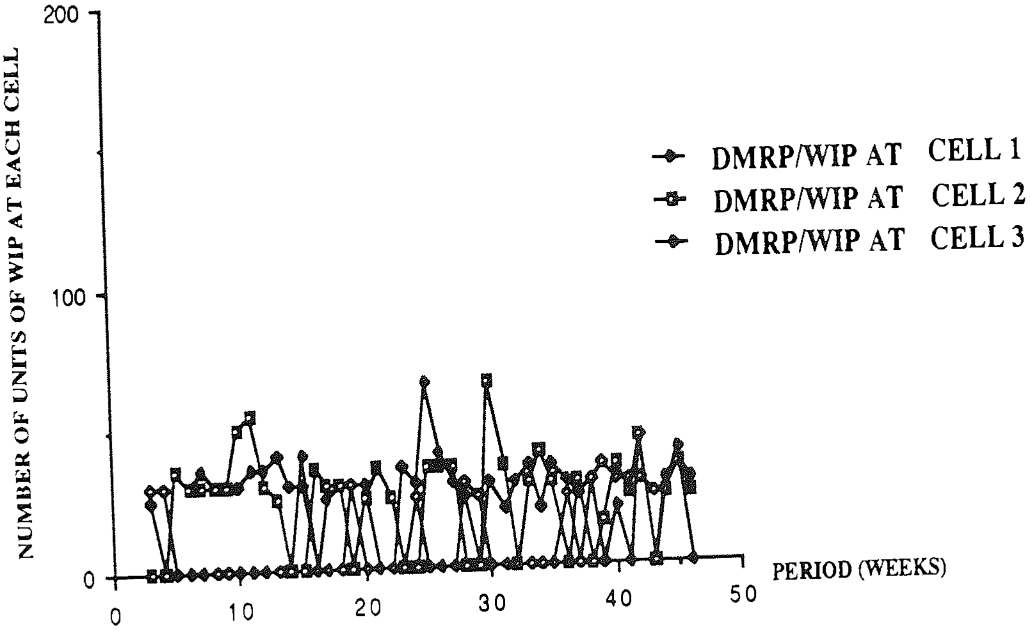

GRAPH OF WIP SAMPLES AT CELLS 1, 2 AND 3
UNDER DMRP ENVIRONMENT

Figure (10.13)

The DMRP WIP levels are considerably lower, because the Just In Time feature of MRP systems is beneficially utilised by adopting the DMRP methodology. This is achieved through the release of manufacturing batches in a Just In Time manner. The orders have been planned to be released when the capacity is available for their manufacture to start. The DMRP system therefore, unlike the conventional approach, does not impose adherence to the MRP suggested order release dates simply to maintain the systems integrity. It can therefore be argued, that the operation of a plant under DMRP system would not impose potentially damaging management policies on a business. The adherence to the conventional MRP approach, would result in higher than necessary work in progress , which leads to lower inventory turnarounds. Figure (10.14), demonstrates the potential benefits of a business operating under DMRP environment.

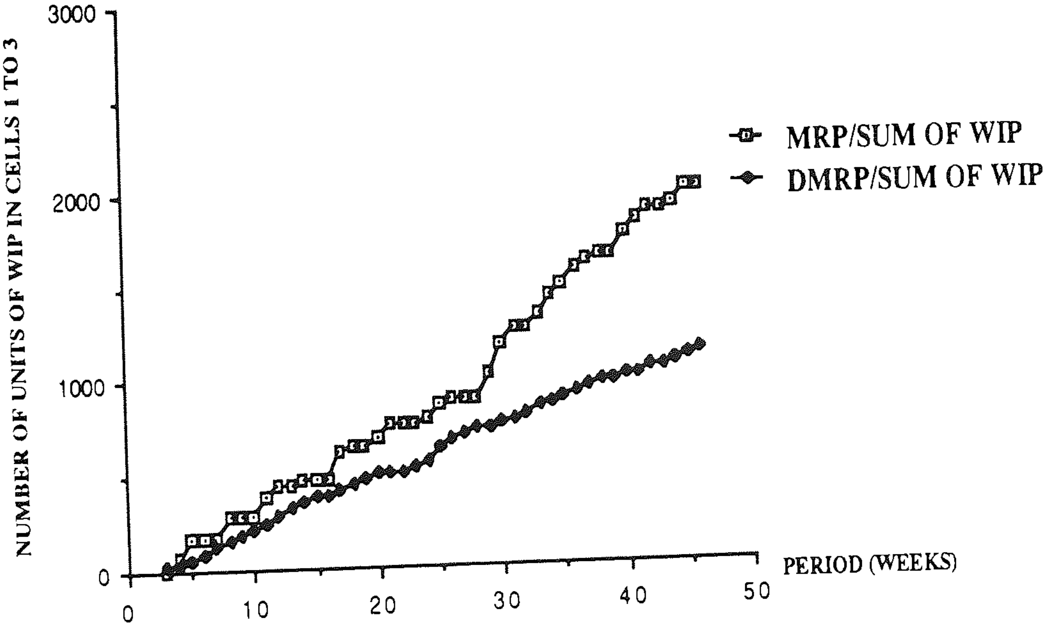

GRAPH OF CUMULATIVE WIP SAMPLES UNDER CONVENTIONAL MRP AND DMRP ENVIRONMENTS

Figure (10.14)

The high amount of cash tied up in a conventional MRP environment, further handicaps a business. The unproductive use of capital in the form of inventories, is one of the major problems. DMRP, it is argued, represents a potential solution to the shortcomings of the conventional systems. DMRP methodology recognises the dynamic nature of businesses and does not impose arbitrary restrictions on the operation of a company simply to maintain the control systems integrity.

Figures (10.15) and (10.16), show the overall performance of the two methodologies.

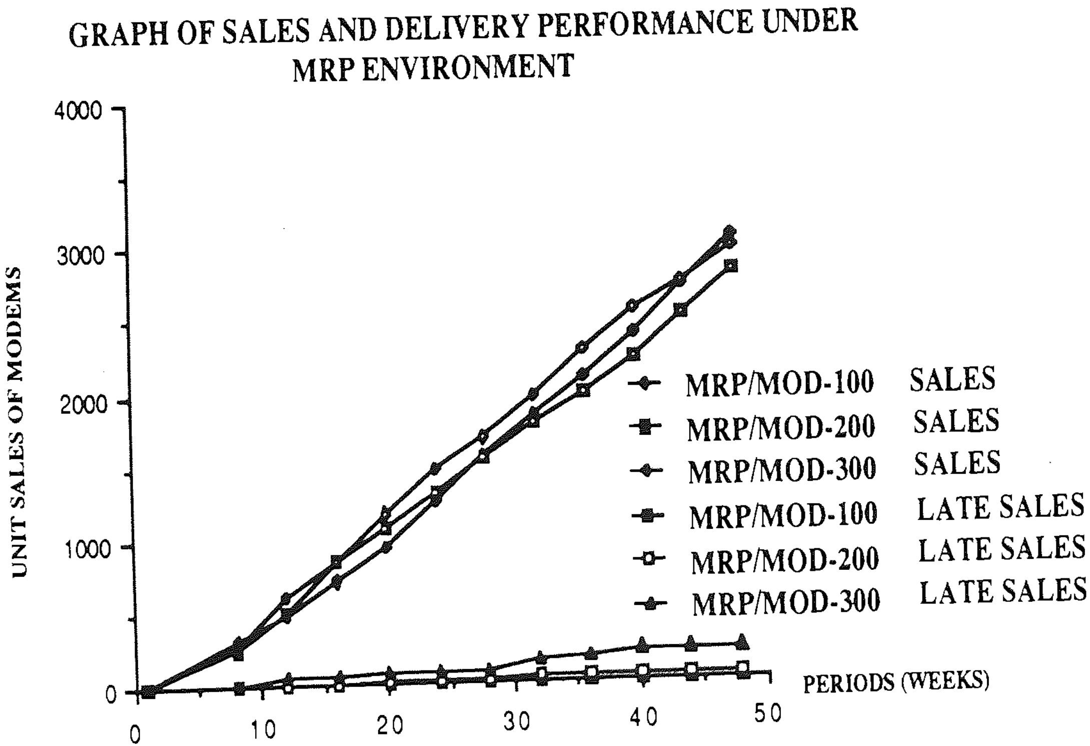


Figure (10.15)

Figure (10.15), highlights the fact that in MRP environments over a period of time, the capacity insensitivity would result in some orders being delivered later than was promised to the customers even when relatively long lead time policy is adopted to overcome occasional capacity overloads. The graph when compared to the DMRP performance in figure (10.16), demonstrates the potential weakness of the conventional MRP systems in respect to customer service.

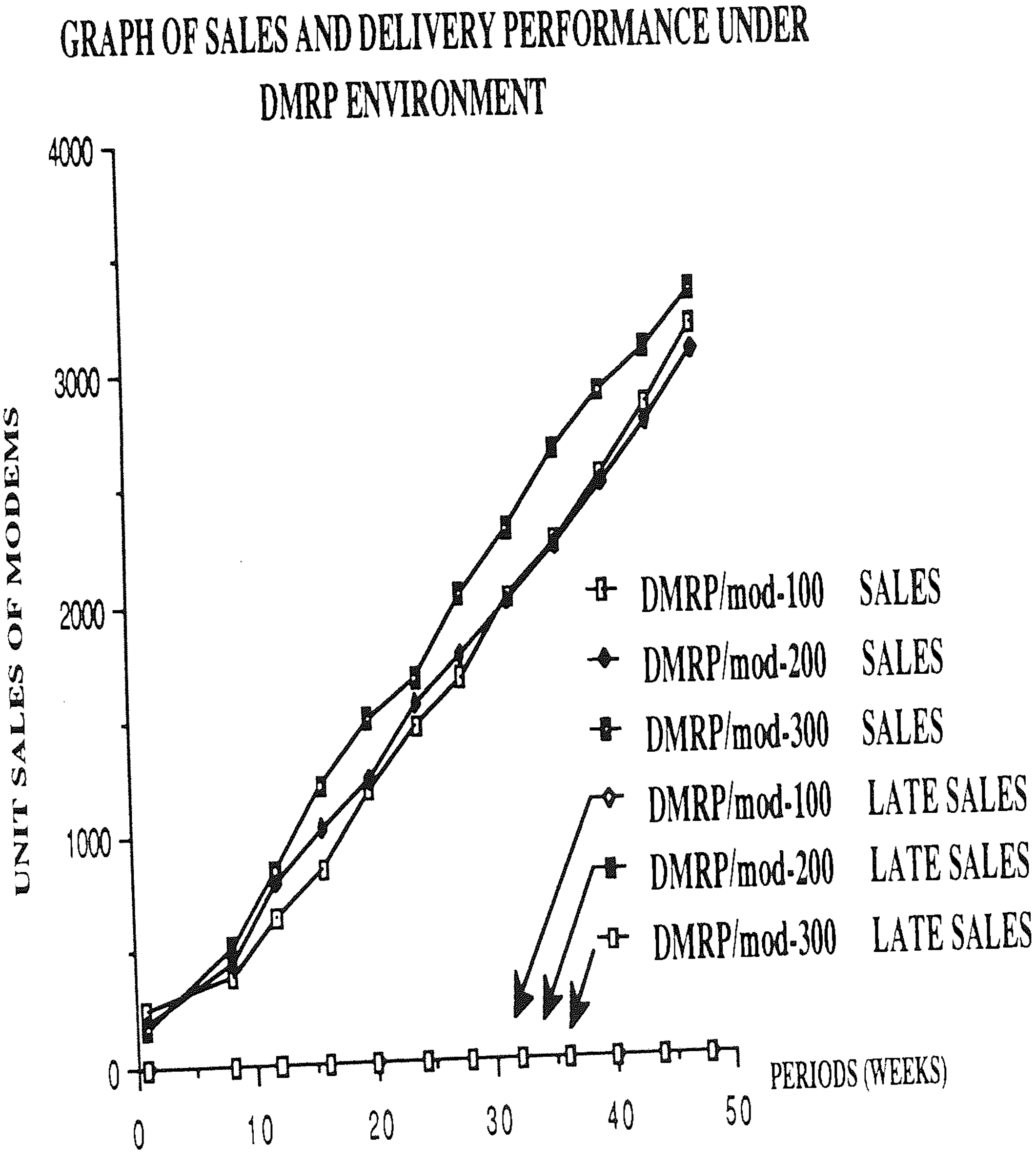


Figure (10.16)

Figure (10.16), by contrast demonstrates the advantages of dynamic scheduling of the DMRP methodology. The fact that the factory model was deterministic, resulted in the DMRP having no late deliveries. In an MRP environment, it is argued, the number of late deliveries could lead to lost sales and customer dissatisfaction. If a company promises to have orders ready by a certain date and it fails to meet the promised delivery date, the customer would soon look for alternative suppliers. In a DMRP environment, the shorter lead times and the potential to predict delivery dates more accurately, could lead to more customer satisfaction and therefore, more sales.

Further experiments utilising a stochastic factory model will clearly be needed to evaluate DMRP performance under more realistic (real world) environments. Here issues such as appropriate levels of safety time which should be added to the technological lead time will have to be investigated.

The important issue to bear in mind is not the quantity of the orders being delivered late, but rather the fact that even with much higher manufacturing lead times than in a DMRP environment, there will always be some orders which will be late. DMRP methodology not only decreases WIP levels and manufacturing lead times, but it also improves delivery performance due to its capacity sensitivity when planning customer orders. In conventional MRP environments, at times of peak customer orders when large batches are placed, the average lead times could prove inadequate to cover the manufacturing lead times of some of the orders, thus over a long period some of the delivery dates would inevitably not be met.

In a conventional MRP environment, when the factory loading is lower than average, and jobs could be manufactured in shorter period of time (due to much less queuing time) the use of fixed lead times is specially damaging. It could be argued that companies should lower their lead times in such circumstances and promise shorter delivery dates to customers. Whilst there is nothing wrong with the above argument, in reality the logistics of changing lead times and the transitory nature of the under loading of the plant tends to lead to no specific action being taken. As a result the suggested work order dates produced by the MRP runs are adhered to thus losing the opportunity to react to the prevailing circumstances by improving customer satisfaction and reducing WIP which in turn would lead to improved cashflow.

10.2 CONCLUDING REMARKS

As a result of the above simulation experiments, it was concluded that the DMRP methodology in a deterministic environment offers significant performance advantages over the conventional MRP approach. The objective of this final stage of the research was to establish if the technique showed sufficient potential for the prototype to be further developed and issues relating to its implementation in an industrial environment be further investigated. The results of the whole research programme led to the conclusion that the methodology offers a unique solution to the problems associated with the implementation of conventional MRP/MRP II systems. The practical implications of adopting the system in an industrial environment will form the bases of future research programmes.

The discussions in chapter 11, will suggest potential areas for further research in the development of the system as an alternative approach to MRP systems.

CHAPTER 11 DISCUSSION OF FURTHER RESEARCH IN DMRP METHODOLOGY

The results of the research programme and the current stage of the DMRP prototype system point to a need to further develop the system to investigate important issues relating to its potential for use in "real world" industrial environments. The following discussions will briefly highlight the main areas of research.

11.1 INVESTIGATION OF POLICY DECISIONS FOR IMPLEMENTING DMRP IN INDUSTRIAL ENVIRONMENTS

Clearly the prototype system will need to be enhanced to a level at which both the suggested orders as well as the feedback loop would be passed on to appropriate cells through the local area network. Both above areas require further programming effort but are not complicated tasks.

The investigation of policy decisions relating to the implementation of the DMRP methodology in industrial environments has already been started at Aston University through a post graduate research programme. The prototype system is being upgraded to allow the performance of the system to be investigated in a stochastic factory simulation model utilising the ATOMS simulator.

11.2 AUTOMATION OF THE DMRP METHODOLOGY

The capacity sensitivity of the DMRP methodology relies on the local cells planning their work orders based on the prevailing work load of each cell. This approach currently requires manual intervention by the cell managers who schedule the jobs accordingly. It is possible however, to develop the system further so that the existing cell loadings could be input into the system and for the DMRP system to schedule the work orders (utilising the technological lead times) based on the current loading of the manufacturing resources within each cell.

A further consequence of this approach would be that each cell manager would set up the parameters under which he would allow the system to make decisions on his behalf and to prompt the manager if specific work orders require special attention. These could for example, include high priority orders which could not be manufactured to customers required delivery date without overtime or sub-contracting to other cells or external sub-contractors.

The decision rules after a feedback signal has been received from a supplier cell could also be automated by adding artificial intelligence rules to the DMRP system. In these situations each cell manager could decide on the type of policy decisions regarding the rescheduling of the tentative orders. The local autonomy of each cell would still be retained with such a development since the system would not make any decision with which the cell manager would not agree. User friendliness of such an addition to the DMRP system would be of paramount importance.

11.3 INVESTIGATION OF DMRP METHODOLOGY IN DISTRIBUTED CIM ENVIRONMENTS

The principle of distributed CIM was developed at Aston University by Lung (1988). The concept of autonomous cells planning their production schedules under local management however, envisaged the use of Conventional MRP methodology within each cell. A research programme is under way to investigate the potential of utilising the DMRP methodology in a distributed CIM environment.

A prototype distributed CIM system which was developed at Aston University will be modified to operate under the DMRP methodology and its performance quantitatively investigated through a series of stochastic simulation experiments.

Distributed data processing of manufacturing planning operations represents a potentially rewarding area of research which could overcome the major shortcomings of the centralised production planning and control systems.

The state of knowledge concerning the use of distributed planning and control in "real world" industrial environments is limited. Research should attempt to evaluate the issues which will need to be considered if the concept of distributed planning is to become a practical option in the field of production planning and control in industrial environments.

11.4 INVESTIGATION OF THE ROLE OF DMRP FOR INTEGRATING MANUFACTURING ENVIRONMENTS

Some manufacturing industries need to offer a range of products and services to retain their customers and to maintain growth. The cellular plant layout and DMRP methodology, offer an opportunity to integrate a diverse range of manufacturing policies and production technologies within a plant.

The use of Kanban, for example, might be appropriate for the manufacture of some of the family of products due to their steady demand and the manufacturing process employed. In a DMRP environment any number of cells could be managed as Kanban cells. The integrated structure of the DMRP system allows the plant manager to have overall control of the manufacturing plant whilst allowing the most appropriate local management techniques to be used.

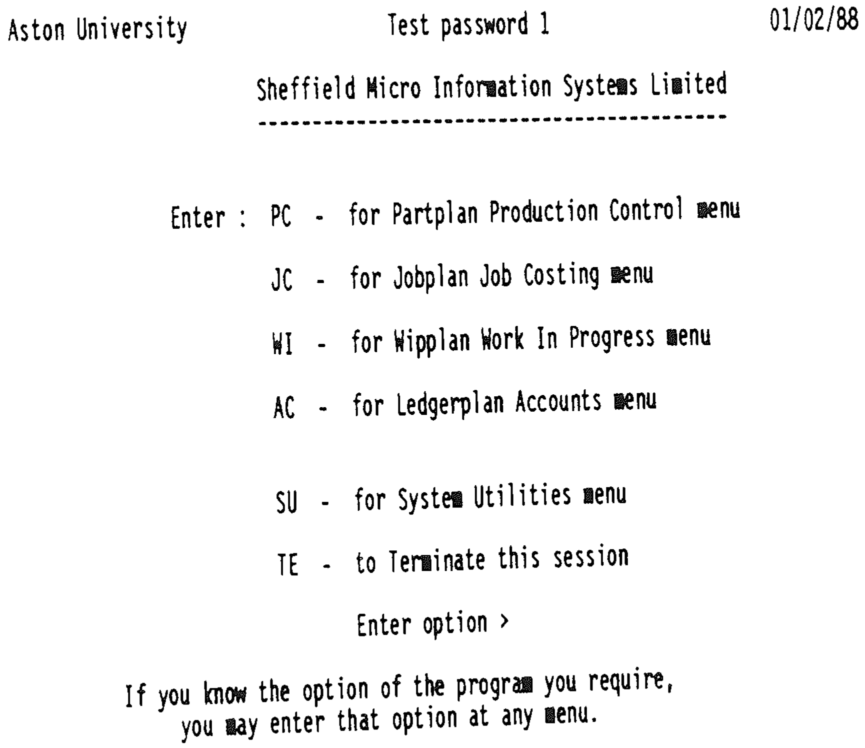
Similarly, a fully automated FMS cell could be operated next to a Kanban cell. The methodology would allow a company to rationalise their manufacturing operations utilising the most efficient management techniques for each of their products or services.

The research will need to establish the practical ground rules for adopting a diverse range of manufacturing techniques within a plant. The developments in computer integrated manufacturing systems still rely on conventional MRP systems to plan their operations. In the light of the evidence presented in the preceding discussions, DMRP would seem the more appropriate tool for integration.

APPENDICES

APPENDIX I AN OVERVIEW OF UNIPLAN MRP II SYSTEM

The Uniplan MRP II system has a wide range of facilities details of which can be found in the Uniplan manuals from Sheffield Micro Information Systems Ltd., Anon (1984). This appendix will show the main facilities which were utilised in the development of the DMRP prototype system. Figure (I.1), shows the main Uniplan menu.

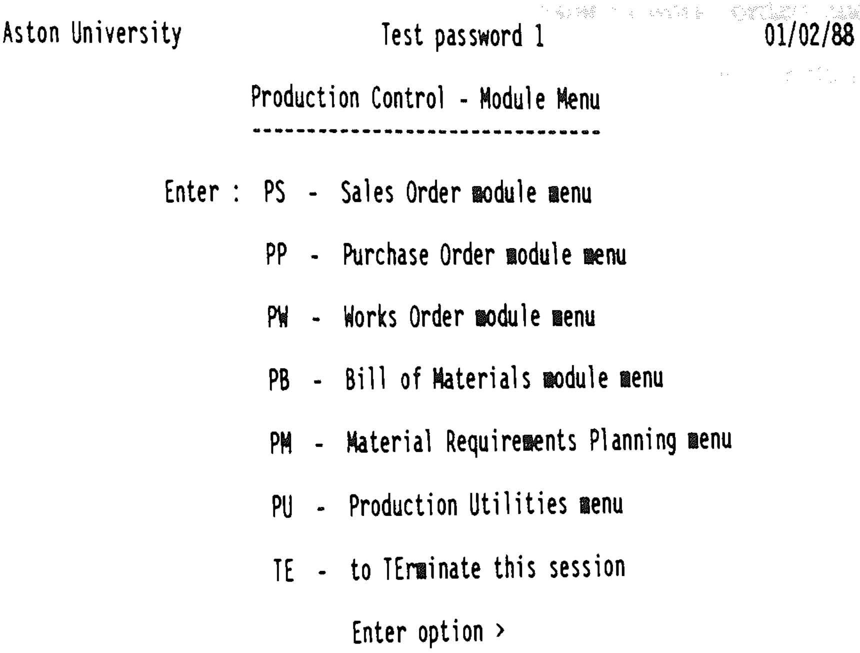


```
Aston University               Test password 1              01/02/88

                   Sheffield Micro Information Systems Limited
                   -------------------------------------------

              Enter :  PC  -  for Partplan Production Control menu

                       JC  -  for Jobplan Job Costing menu

                       WI  -  for Wipplan Work In Progress menu

                       AC  -  for Ledgerplan Accounts menu


                       SU  -  for System Utilities menu

                       TE  -  to Terminate this session

                              Enter option >

          If you know the option of the program you require,
              you may enter that option at any menu.
```

Figure (I.1)

I.1 PARTPLAN OVERVIEW

PART PLAN offers integrated Sales order, Purchase Order, Work Order, Bill of material and Stock maintenance facilities as well as net requirements planning through the MRP module. Figure (I.2) shows the Production Control Module Menu.

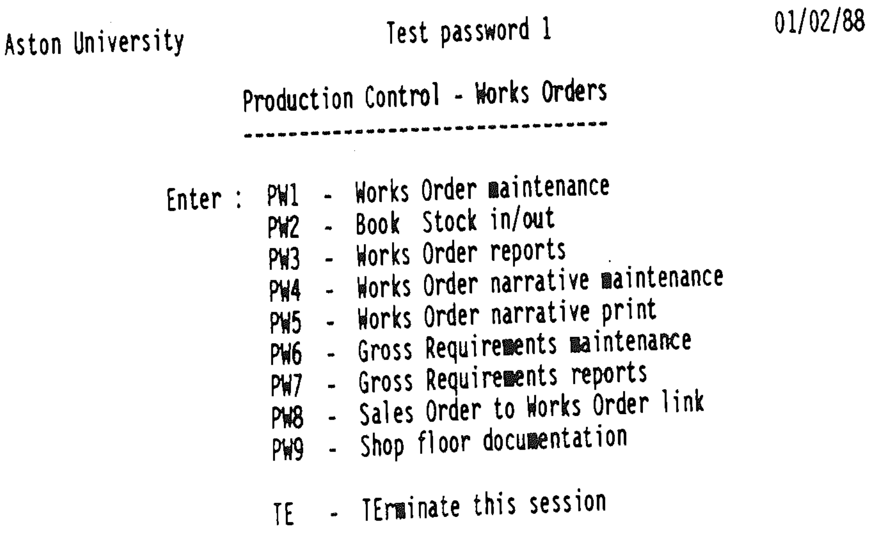


```
Aston University            Test password 1            01/02/88

                    Production Control - Module Menu
                    --------------------------------

               Enter :  PS  -  Sales Order module menu

                        PP  -  Purchase Order module menu

                        PW  -  Works Order module menu

                        PB  -  Bill of Materials module menu

                        PM  -  Material Requirements Planning menu

                        PU  -  Production Utilities menu

                        TE  -  to TErminate this session

                               Enter option >
```

Figure (I.2)

I.2 WORKS ORDERS

Figure (I.3), shows the works order processing menu.



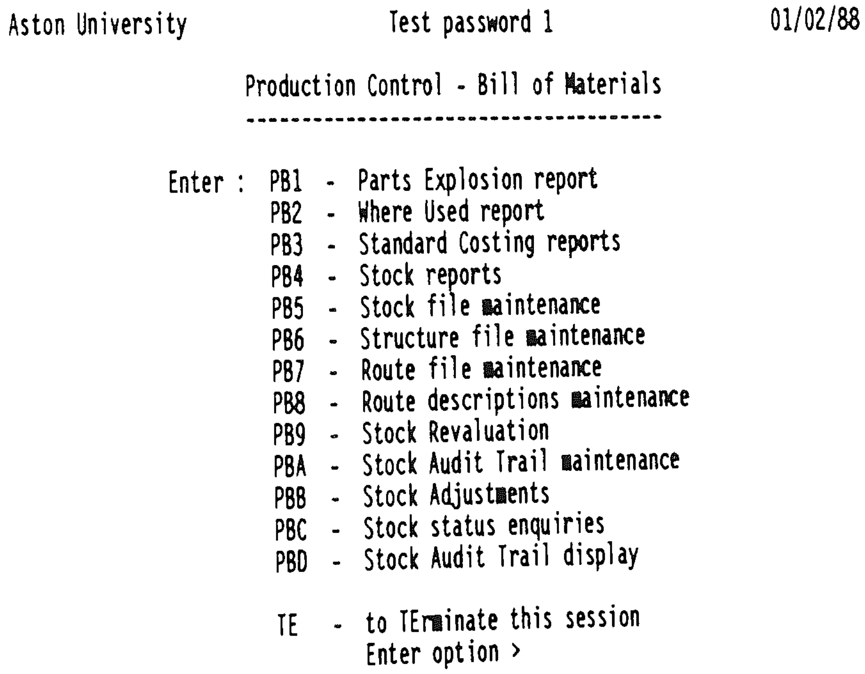
```
Aston University            Test password 1            01/02/88

                    Production Control - Works Orders
                    ---------------------------------

               Enter :  PW1  -  Works Order maintenance
                        PW2  -  Book  Stock in/out
                        PW3  -  Works Order reports
                        PW4  -  Works Order narrative maintenance
                        PW5  -  Works Order narrative print
                        PW6  -  Gross Requirements maintenance
                        PW7  -  Gross Requirements reports
                        PW8  -  Sales Order to Works Order link
                        PW9  -  Shop floor documentation

                        TE   -  TErminate this session
```

Figure (I.3)

This module allows users to enter and maintain works orders and perform all works order processing functions. These include allocation of parts to orders, manual issue of parts, interface to WIP module and booking of finished goods into stock.

I.3 BILL OF MATERIALS

Figure (I.4), shows the Bill of Materials menu.



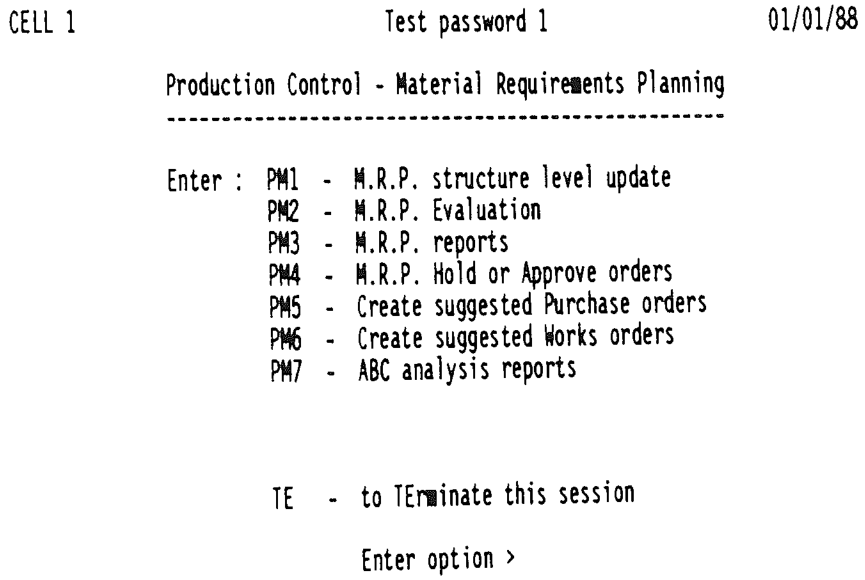
```
Aston University              Test password 1              01/02/88

                   Production Control - Bill of Materials
                   --------------------------------------

          Enter :  PB1  -  Parts Explosion report
                   PB2  -  Where Used report
                   PB3  -  Standard Costing reports
                   PB4  -  Stock reports
                   PB5  -  Stock file maintenance
                   PB6  -  Structure file maintenance
                   PB7  -  Route file maintenance
                   PB8  -  Route descriptions maintenance
                   PB9  -  Stock Revaluation
                   PBA  -  Stock Audit Trail maintenance
                   PBB  -  Stock Adjustments
                   PBC  -  Stock status enquiries
                   PBD  -  Stock Audit Trail display

                   TE   -  to TErminate this session
                           Enter option >
```

Figure (I.4)

This module is used to set up and maintain the basic stock, structures and route data associated with Partplan. These include multi level structures, indented explosions, indented implosion, where used, price analysis and cost roll up via bill of materials.

I.4 MATERIAL REQUIREMENTS PLANNING

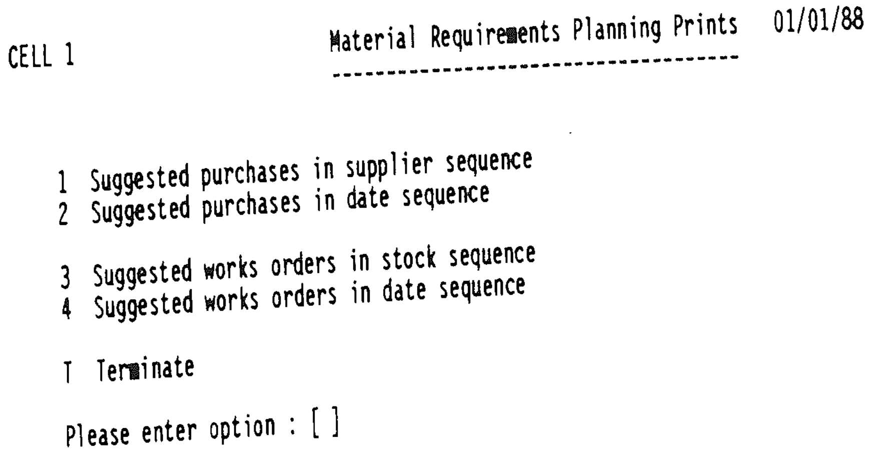
Figure (I.5), shows the MRP planning menu. Uniplan is a Net Requirements Planning system since it takes account of existing works orders and purchase orders and the current stock positions. The dates for suggested works orders and purchase orders take account of the delivery lead time on the stock file.



```
CELL 1                         Test password 1                01/01/88

            Production Control - Material Requirements Planning
            ---------------------------------------------------

            Enter : PM1  -  M.R.P. structure level update
                    PM2  -  M.R.P. Evaluation
                    PM3  -  M.R.P. reports
                    PM4  -  M.R.P. Hold or Approve orders
                    PM5  -  Create suggested Purchase orders
                    PM6  -  Create suggested Works orders
                    PM7  -  ABC analysis reports


                    TE   -  to TErminate this session

                            Enter option >
```

Figure (I.5)

Option PM3 will print out the analysis created in option PM2. Figure (I.6), shows the types of reports available in PM3.

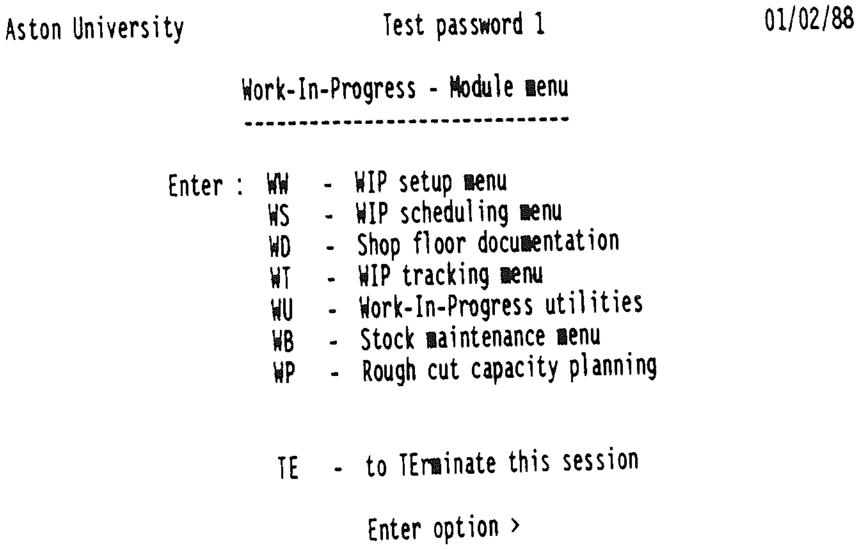


```
                          Material Requirements Planning Prints   01/01/88
CELL 1                    -------------------------------------


    1  Suggested purchases in supplier sequence
    2  Suggested purchases in date sequence

    3  Suggested works orders in stock sequence
    4  Suggested works orders in date sequence

    T  Terminate

    Please enter option : [ ]
```

Figure (I.6)

1.5 WORK-IN-PROGRESS

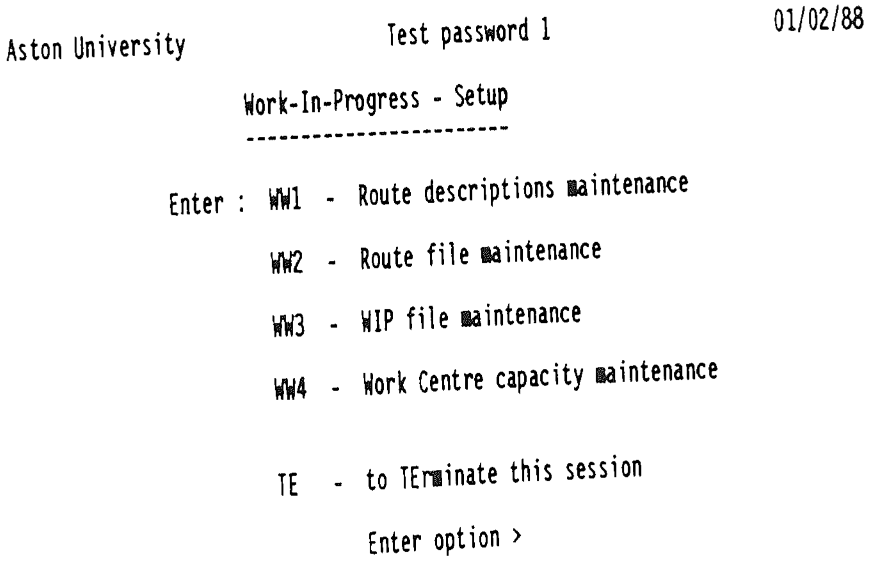
Figure (I.7), shows the main Work-IN-Progress (WIP) menu.



```
Aston University              Test password 1              01/02/88

                     Work-In-Progress - Module menu
                     ------------------------------

              Enter :  WW  -  WIP setup menu
                       WS  -  WIP scheduling menu
                       WD  -  Shop floor documentation
                       WT  -  WIP tracking menu
                       WU  -  Work-In-Progress utilities
                       WB  -  Stock maintenance menu
                       WP  -  Rough cut capacity planning


                       TE  -  to TErminate this session

                              Enter option >
```

Figure (I.7)

Options WW and WS were utilised in the creation of capacity sensitive work order schedules in the DMRP methodology. Figure (I.8), shows the WIP Setup menu.



```
Aston University              Test password 1              01/02/88

                     Work-In-Progress - Setup
                     ------------------------

              Enter :  WW1 -  Route descriptions maintenance

                       WW2 -  Route file maintenance

                       WW3 -  WIP file maintenance

                       WW4 -  Work Centre capacity maintenance


                       TE  -  to TErminate this session

                              Enter option >
```

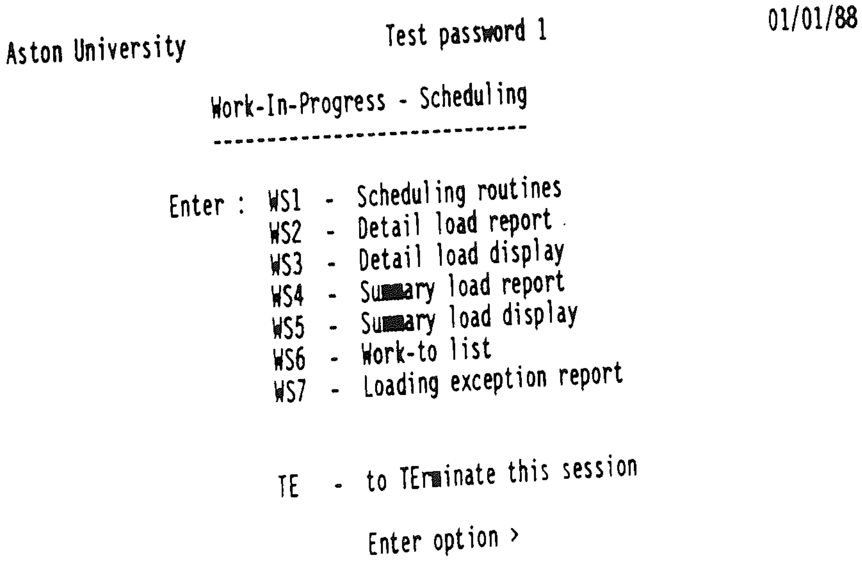
Figure (I.8)

Options WW1 and WW2 are utilised to create the manufacturing routing data. The technological lead time which was referred to in the main discussions, is calculated using the routing data. Option WW4 allows the user to define the total capacity of each work centre. This information is then used to determine capacity availability when scheduling suggested works orders.

Option WW3 allows the user to maintain the WIP file. The essential element offered by this option is the ability to modify order due dates and operation dates and elements on the route to allow rescheduling of individual works orders depending on the transient capacity conditions. DMRP prototype system utilises this facility to schedule works orders in a capacity sensitive manner. An example is included in appendix II.

1.6 WIP SCHEDULING

Having created a WIP job in the system, the scheduling module will allow a job to be scheduled using Latest Start Date algorithm.



```
Aston University              Test password 1               01/01/88

                     Work-In-Progress - Scheduling
                     -----------------------------

               Enter :  WS1  -  Scheduling routines
                        WS2  -  Detail load report
                        WS3  -  Detail load display
                        WS4  -  Summary load report
                        WS5  -  Summary load display
                        WS6  -  Work-to list
                        WS7  -  Loading exception report


                        TE   -  to TErminate this session

                                Enter option >
```

Figure (I.9)

Option WS1 is used to carry out the scheduling routine.

Figure (I.10), shows the the facilities within this option.

```
CELL 1                  Work In Progress Scheduling Routine       01/01/88
                        -----------------------------------



        Schedule Infor■ation kept fro■  : 01/01/87        1  Latest Start Date
                                    to  : 01/12/88

        Include Analysis by Work Centre : Y
                                                          99 Recreate Schedule file
        Include Analysis by Date        : Y
                                                          T  to Ter■inate progra■
        Scheduled Days per Week         : 5
                                                           Select Option : [1 ]
        A■end Header details (Y/N)      :[N]
```

Figure (I.10)

Options WS2, WS3, WS4 and WS5 produce various types of analysis reports or on screen displays of the current capacity loading. These facilities can be used by the cell managers to evaluate the transient capacity conditions and to reschedule works orders if there are capacity over loads. An example of the use of the above facilities in the DMRP system is included in appendix II.

The above modules provide the facilities which are required to run the DMRP system utilising a conventional MRP II system.

APPENDIX II DMRP METHODOLOGY UTILISING THE UNIPLAN MRP II SYSTEM

The DMRP methodology described in the chapters 8 and 9, utilises essentially the same range of facilities which are commonly available in micro based MRP II systems. The prototype system as it was stated earlier was developed using the commercially available UNIPLAN MRP II system. This appendix will provide additional information about the way DMRP methodology was operated using the UNIPLAN system. The specific menu options will be highlighted along with some examples of the way capacity sensitivity is achieved through rescheduling of works orders based on transient capacity conditions.

II.1 CELL CONTROLLERS USE OF UNIPLAN MENUS AND ACTIONS

Figure (II.1), summarises the cell controller's activities and the menu options utilised for each action. The important feature of the DMRP methodology with respect to overall plant management, lies in the fact that responsibility for planning of the works orders is passed on to the cell managers, who would have to produce the customer orders. The cell controller's UNIPLAN MRP II system simply contains a single level bill of material for every product which the company might sell, which simply states the final assembly supplier for each of the products. The execution of the MRP run therefore, produces the tentative works orders with the customer's required quantity and preferred delivery date.

CELL CONTROLLERS
USE OF UNIPLAN
MENUS AND ACTIONS

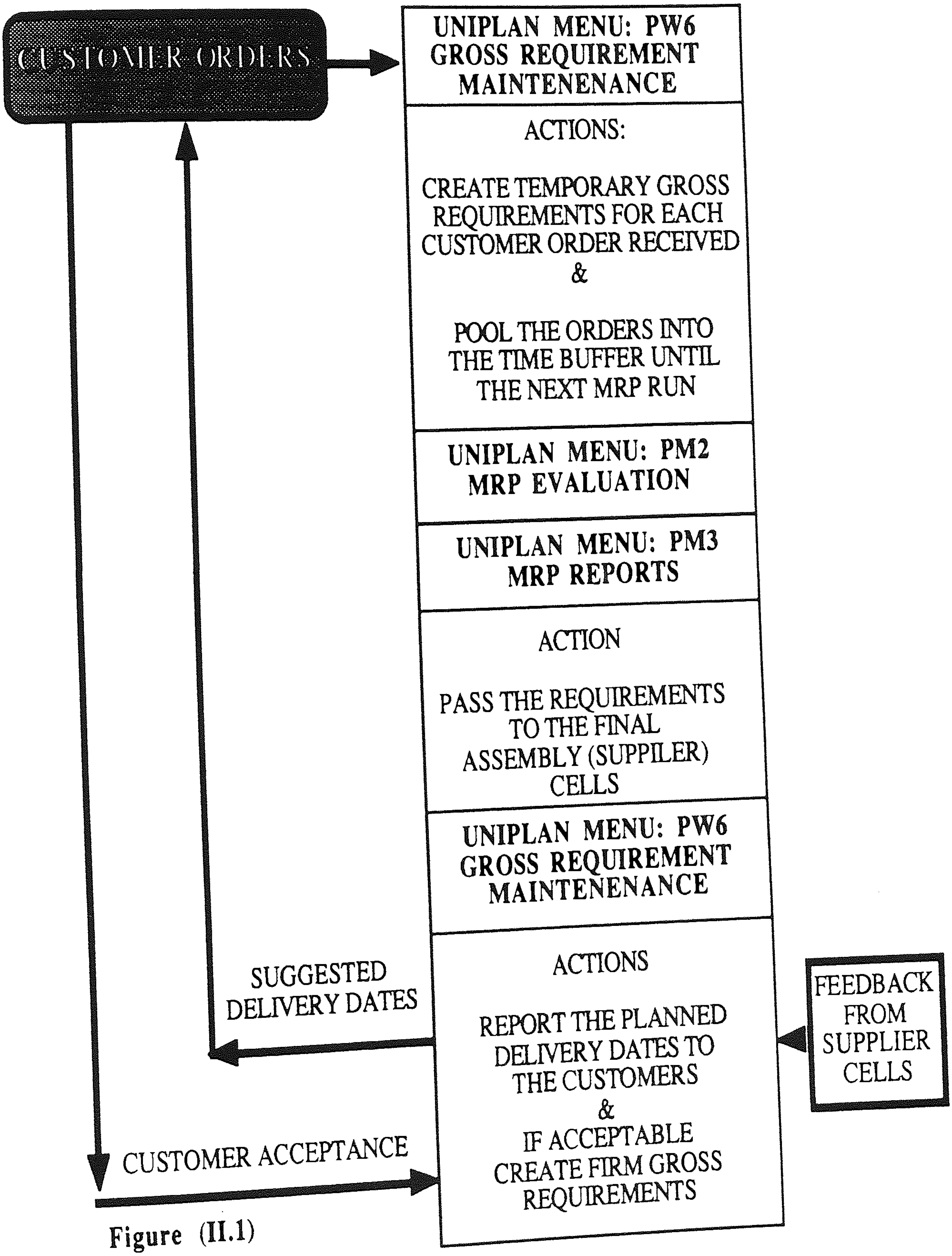


Figure (II.1)

II.2 FINAL ASSEMBLY CELL MANAGERS USE OF UNIPLAN MENUS AND ACTIONS

Figure (II.2), summarises the final assembly cell managers use of UNIPLAN menus and actions. The final assembly cell manager is responsible for the delivery of the finished product to the customer. The delivery date will obviously have to be as far as possible what the customer has requested. The MRP run in this case would be used to plan the suggested works orders based on the current capacity conditions. If a product is wholly manufactured in a cell, then there would not be any need to consult other supplier cells. The works orders will then be scheduled and the delivery date will be passed on to the cell controller awaiting feedback from the customer.

If however, a particular order requires sub-assemblies from other supplier cells then those requirements are passed on to the supplier cells awaiting their response as to when they can deliver. If the delivery dates are later than that which was tentatively planned by the customer cell, then the works orders will be rescheduled accordingly and the actual delivery date to the customer will be passed on to the cell controller. An example of the rescheduling process will be shown in section (II.4) of this appendix. The customer order pooled referred to in figure (II.2), would be used to structure the planning processes based on the time taken to respond to an order or a feedback from the supplier cells. This approach would clearly need to be tailored to the particular environmental conditions of each company.

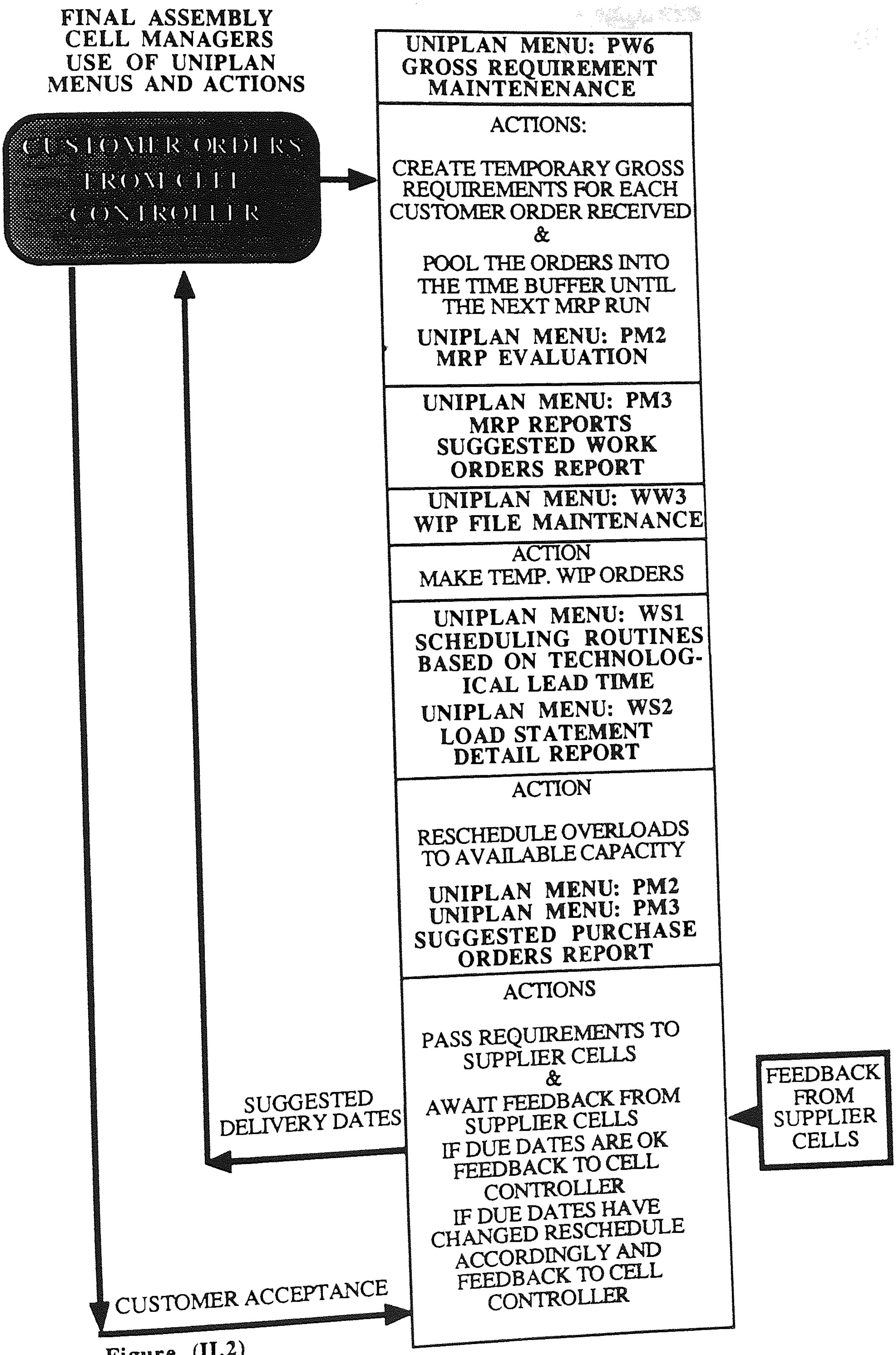

FINAL ASSEMBLY CELL MANAGERS USE OF UNIPLAN MENUS AND ACTIONS
CUSTOMER ORDERS FROM CELL CONTROLLER
UNIPLAN MENU: PW6 GROSS REQUIREMENT MAINTENENANCE
ACTIONS:
CREATE TEMPORARY GROSS REQUIREMENTS FOR EACH CUSTOMER ORDER RECEIVED
&
POOL THE ORDERS INTO THE TIME BUFFER UNTIL THE NEXT MRP RUN
UNIPLAN MENU: PM2 MRP EVALUATION
UNIPLAN MENU: PM3 MRP REPORTS SUGGESTED WORK ORDERS REPORT
UNIPLAN MENU: WW3 WIP FILE MAINTENANCE
ACTION
MAKE TEMP. WIP ORDERS
UNIPLAN MENU: WS1 SCHEDULING ROUTINES BASED ON TECHNOLOGICAL LEAD TIME
UNIPLAN MENU: WS2 LOAD STATEMENT DETAIL REPORT
ACTION
RESCHEDULE OVERLOADS TO AVAILABLE CAPACITY
UNIPLAN MENU: PM2
UNIPLAN MENU: PM3
SUGGESTED PURCHASE ORDERS REPORT
ACTIONS
PASS REQUIREMENTS TO SUPPLIER CELLS
&
AWAIT FEEDBACK FROM SUPPLIER CELLS
IF DUE DATES ARE OK FEEDBACK TO CELL CONTROLLER
IF DUE DATES HAVE CHANGED RESCHEDULE ACCORDINGLY AND FEEDBACK TO CELL CONTROLLER
FEEDBACK FROM SUPPLIER CELLS
SUGGESTED DELIVERY DATES
CUSTOMER ACCEPTANCE

Figure (II.2)

II.3 SUB-ASSEMBLY SUPPLIER CELL MANAGERS USE OF UNIPLAN MENUS AND ACTIONS

The sub-assembly supplier cell refers to any plant-wide cell which supplies parts to the cells which are involved in the manufacture of a product. These cells are referred to as dependent cells.

Clearly the number dependencies should be limited to reduce the planning loop transactions in a real world manufacturing environment. Figure (II.3), summarises the cell managers use of UNIPLAN menus and actions.

The procedures would be the same for any other supplier cell. The UNIPLAN MRP II system provided all the facilities which are required to operate a plant under DMRP environment.

The fact that the software can be configured to run on a multi company basis is particularly useful in a cellular manufacturing environment. The software automatically creates separate data files for each configured company. Each manufacturing cell therefore, could be set up as an autonomous cell without any modifications to the software.

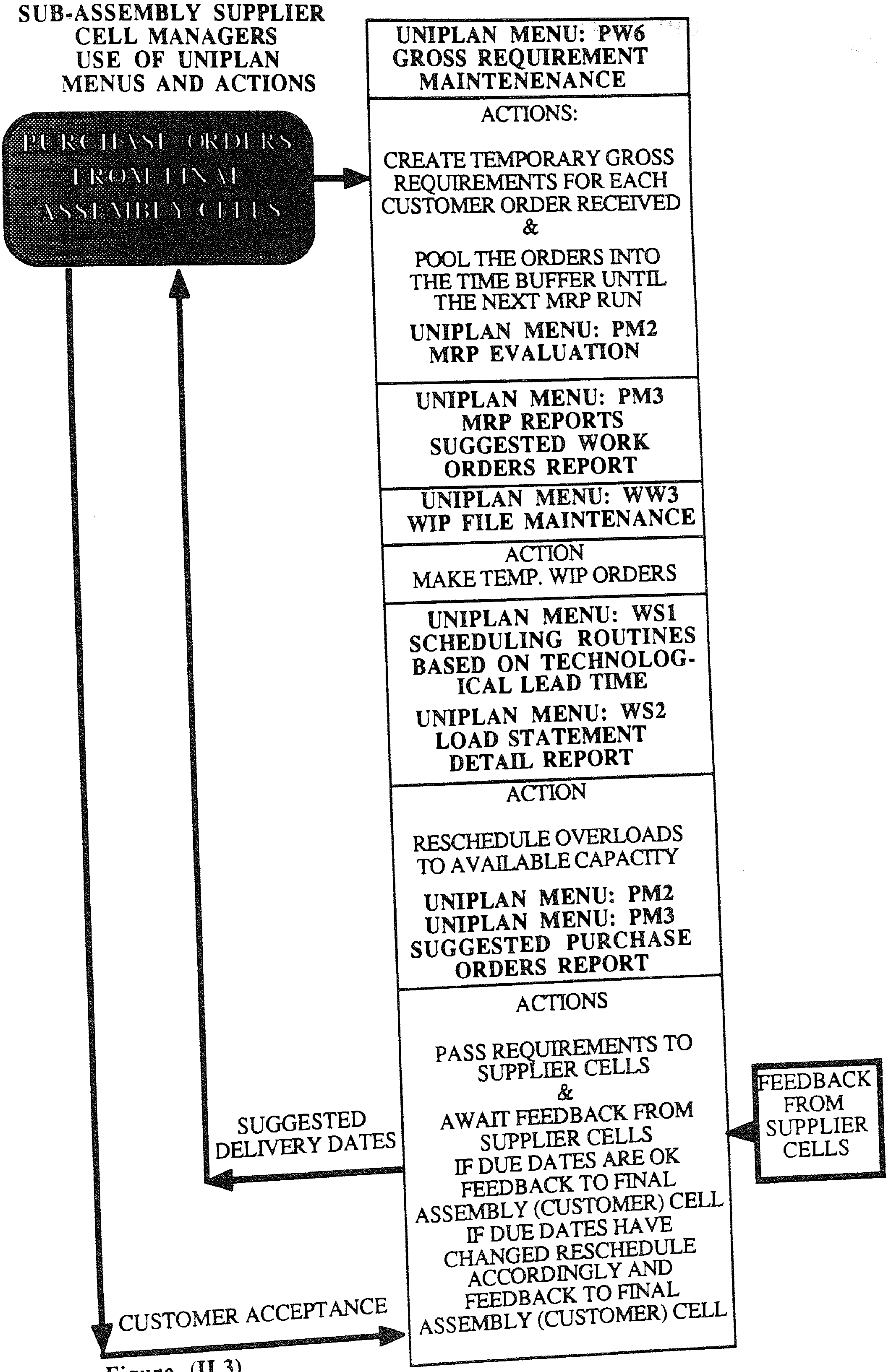
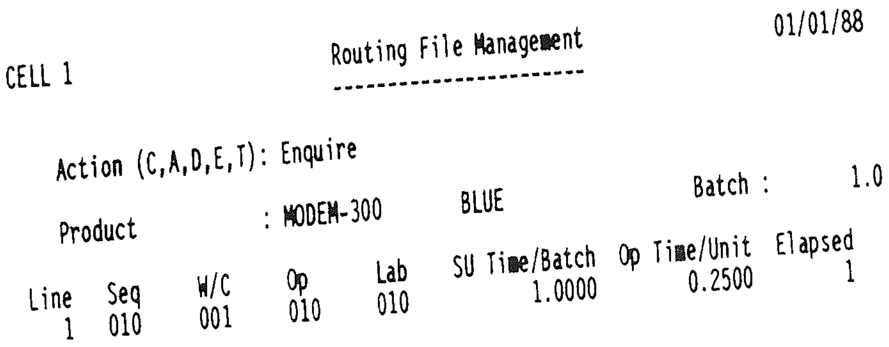

SUB-ASSEMBLY SUPPLIER CELL MANAGERS USE OF UNIPLAN MENUS AND ACTIONS
PURCHASE ORDERS FROM FINAL ASSEMBLY CELLS
UNIPLAN MENU: PW6
GROSS REQUIREMENT MAINTENENANCE
ACTIONS:
CREATE TEMPORARY GROSS REQUIREMENTS FOR EACH CUSTOMER ORDER RECEIVED
&
POOL THE ORDERS INTO THE TIME BUFFER UNTIL THE NEXT MRP RUN
UNIPLAN MENU: PM2
MRP EVALUATION
UNIPLAN MENU: PM3
MRP REPORTS
SUGGESTED WORK ORDERS REPORT
UNIPLAN MENU: WW3
WIP FILE MAINTENANCE
ACTION
MAKE TEMP. WIP ORDERS
UNIPLAN MENU: WS1
SCHEDULING ROUTINES BASED ON TECHNOLOGICAL LEAD TIME
UNIPLAN MENU: WS2
LOAD STATEMENT DETAIL REPORT
ACTION
RESCHEDULE OVERLOADS TO AVAILABLE CAPACITY
UNIPLAN MENU: PM2
UNIPLAN MENU: PM3
SUGGESTED PURCHASE ORDERS REPORT
ACTIONS
PASS REQUIREMENTS TO SUPPLIER CELLS
&
AWAIT FEEDBACK FROM SUPPLIER CELLS
IF DUE DATES ARE OK FEEDBACK TO FINAL ASSEMBLY (CUSTOMER) CELL
IF DUE DATES HAVE CHANGED RESCHEDULE ACCORDINGLY AND FEEDBACK TO FINAL ASSEMBLY (CUSTOMER) CELL
FEEDBACK FROM SUPPLIER CELLS
SUGGESTED DELIVERY DATES
CUSTOMER ACCEPTANCE

Figure (II.3)

II.4 AN EXAMPLE OF DMRP RESCHEDULING METHODOLOGY

To demonstrate the rescheduling procedure of the DMRP methodology, an example of a works orders (number 103), will be shown using screen prints from the DMRP prototype system.

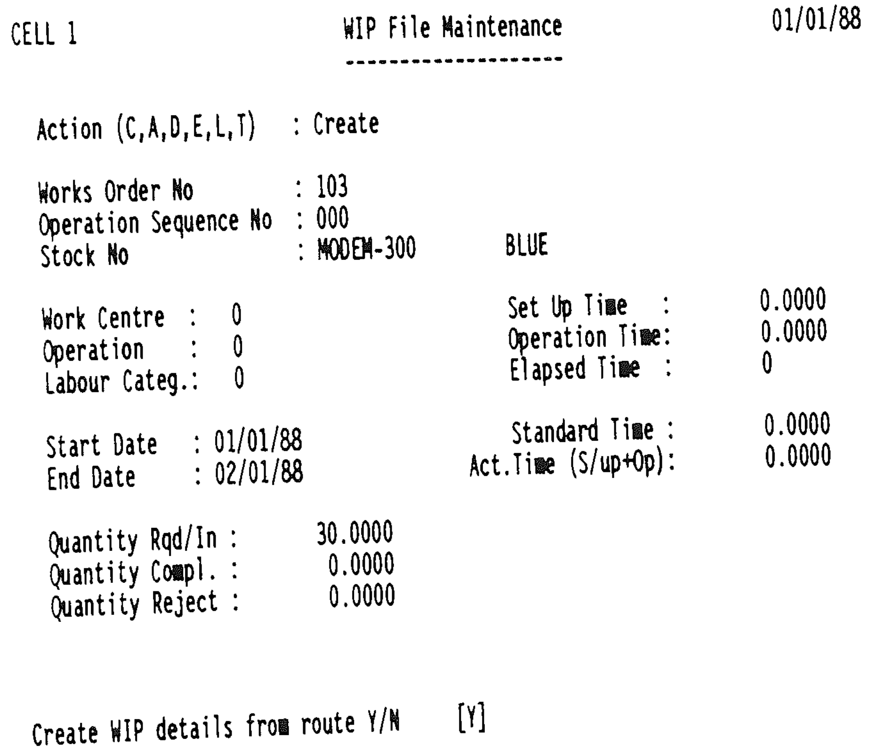
The UNIPLAN system schedules works orders based on a fixed elapsed time which the user must specify when creating the routing data. This facility was utilised to create the first tentative schedule using the WS menu (works order scheduling) of the system. Essentially the MRP system suggests orders to the nearest whole day, therefore, the minimum elapsed time for a works order would have to be one day. This field would not be used if there are many operations to be performed within a cell before an order is completed. In this case, as figure (II.4), shows the manufacturing route consists of a set up and one operations. The set up time is one hour and the operation time per unit is 0.25 hour. The elapsed time is one day.



```
                                                                 01/01/88
CELL 1                         Routing File Management
                               -----------------------

    Action (C,A,D,E,T): Enquire
                                                        Batch :       1.0
    Product            : MODEM-300       BLUE

                                   Lab   SU Time/Batch  Op Time/Unit  Elapsed
  Line   Seq    W/C     Op                     1.0000        0.2500         1
     1   010    001     010        010
```

Figure (II.4)

If we assume that an order for 30 units of MODEM-300 has been received, we can follow the process of creating an order through to its first schedule and the subsequent capacity sensitive rescheduling of the works order (no 103). Figure (II.5) shows the WW3 screen and the works order 103 being created the required date of the product is 02/01/88. Based on the minimum elapsed time of 1 day, the start date is scheduled a day earlier. (i.e., 01/01/88).

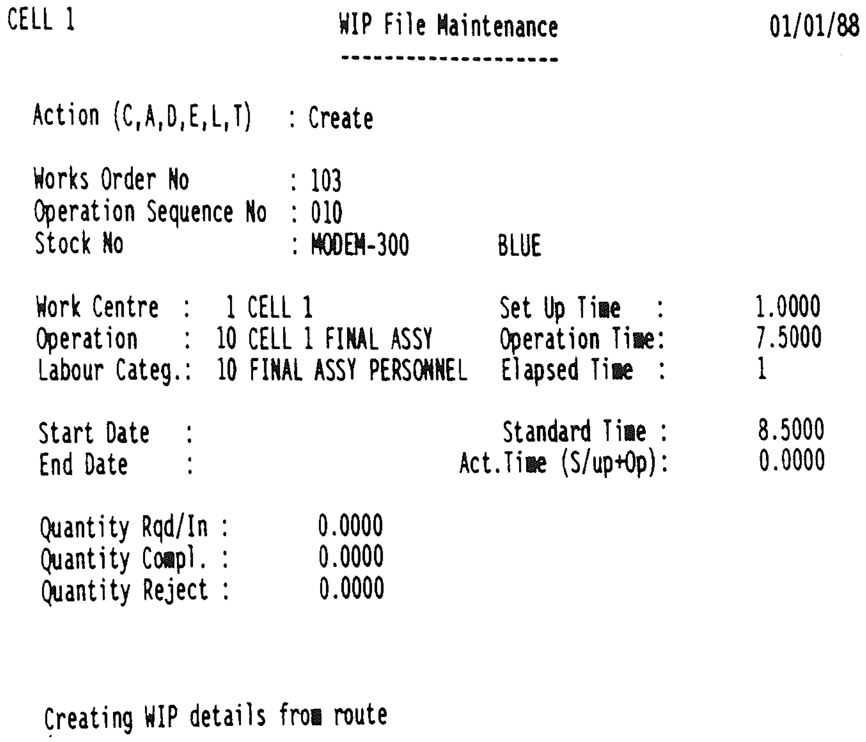


```
CELL 1                       WIP File Maintenance                01/01/88
                             --------------------

  Action (C,A,D,E,L,T)    : Create

  Works Order No          : 103
  Operation Sequence No   : 000
  Stock No                : MODEM-300       BLUE

  Work Centre  :   0                        Set Up Time    :        0.0000
  Operation    :   0                        Operation Time:         0.0000
  Labour Categ.:   0                        Elapsed Time   :        0

  Start Date   : 01/01/88                   Standard Time :         0.0000
  End Date     : 02/01/88                 Act.Time (S/up+Op):       0.0000

  Quantity Rqd/In :       30.0000
  Quantity Compl. :        0.0000
  Quantity Reject :        0.0000


  Create WIP details from route Y/N      [Y]
```

Figure (II.5)

At the bottom left hand side of the screen the quantity of 30 units is then input. The screen will then read 'Create WIP details from route Y/N ' The cell manager would type in Y.

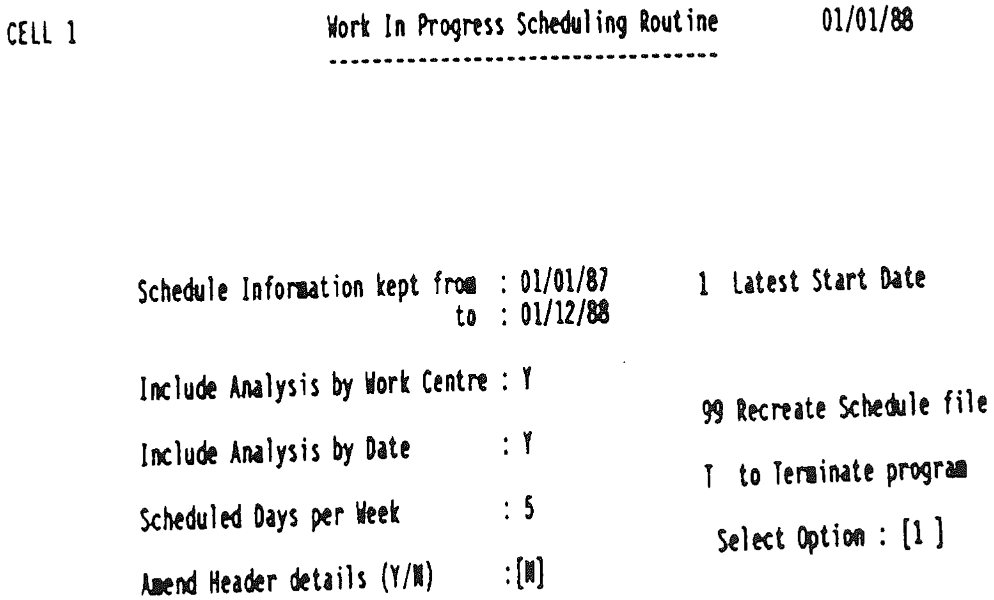
FIgure (II.6), shows the calculation of the technological lead time for the works order 103. This calculation is automatically carried out by the system. At this point a tentative works order has been created.



```
CELL 1                        WIP File Maintenance               01/01/88
                              --------------------

  Action (C,A,D,E,L,T)   : Create

  Works Order No         : 103
  Operation Sequence No  : 010
  Stock No               : MODEM-300       BLUE

  Work Centre  :   1 CELL 1                 Set Up Time    :      1.0000
  Operation    :  10 CELL 1 FINAL ASSY      Operation Time:      7.5000
  Labour Categ.:  10 FINAL ASSY PERSONNEL   Elapsed Time   :      1

  Start Date   :                             Standard Time :      8.5000
  End Date     :                        Act.Time (S/up+Op):      0.0000

  Quantity Rqd/In :       0.0000
  Quantity Compl. :       0.0000
  Quantity Reject :       0.0000


  Creating WIP details from route
```

Figure (II.6)

The scheduling procedure is then executed using menu option WS1 Figure (II.7), shows the current default settings.



```
CELL 1                 Work In Progress Scheduling Routine        01/01/88
                       -----------------------------------



      Schedule Information kept from  : 01/01/87      1  Latest Start Date
                                  to  : 01/12/88

      Include Analysis by Work Centre : Y
                                                      99 Recreate Schedule file
      Include Analysis by Date        : Y
                                                      T  to Terminate program
      Scheduled Days per Week         : 5
                                                       Select Option : [1 ]
      Amend Header details (Y/N)      :[N]
```

Figure (II.7)

Figure (II.8), shows the works order 103 being scheduled.

```
                    Updating Schedule file


        Creating New schedule for W/O     103
        Processing Work Centre            001
```

Figure (II.8)

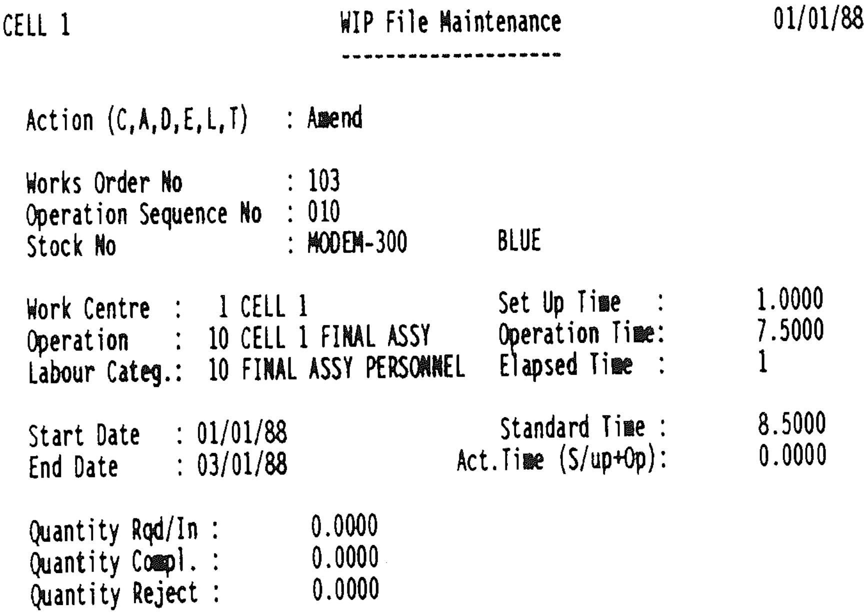
Having scheduled the works order 103, option WS2 is used to print out a work centre loading report. Figure (II.9), shows the current loading conditions including the newly created works order 103.

```
CELL 1                 WORK CENTRE LOADING REPORT   (W/O)     Date : 01/01/88


<--W/O No-&-Stock item-<-----Work Centre------> Capacity/Wk     Period      Hours

100       MODEM-100     1 CELL 1                    40.0000     01/01/88     3.5020
                                                                          -----------
                                                                             3.5020

                                                                          ===========
                                                                             3.5020


103       MODEM-300     1 CELL 1                    40.0000     01/01/88     8.5000
                                                                          -----------
                                                                             8.5000

                                                                          ===========
                                                                             8.5000


105       MODEM-100     1 CELL 1                    40.0000     02/01/88     3.0850
                                                                          -----------
                                                                             3.0850

                                                                          ===========
                                                                             3.0850
```

Figure (II.9)

The work centre operates a five day week with daily capacity of eight hours per day. The cell manager can readily see that the due date (02/01/88), can not be met, since works order 100 is due to start at 01/01/88 with a work content of 3.502 hours. The works order 103 can still be scheduled to start on the same day but since the work content is 8.500 hours the due date will need to be rescheduled to 03/01/88.

Menu option WW3, is then used to reschedule the due date of the works order 103. Figure (II.10), shows the Amend option which is used to reschedule the due date.



```
CELL 1                      WIP File Maintenance                01/01/88
                            --------------------

  Action (C,A,D,E,L,T)   : Amend

  Works Order No         : 103
  Operation Sequence No  : 010
  Stock No               : MODEM-300        BLUE

  Work Centre  :   1 CELL 1                 Set Up Time    :       1.0000
  Operation    :  10 CELL 1 FINAL ASSY      Operation Time:        7.5000
  Labour Categ.:  10 FINAL ASSY PERSONNEL   Elapsed Time   :       1

  Start Date   : 01/01/88                   Standard Time :        8.5000
  End Date     : 03/01/88                Act.Time (S/up+Op):       0.0000

  Quantity Rqd/In :       0.0000
  Quantity Compl. :       0.0000
  Quantity Reject :       0.0000
```

Figure (II.10)

The works order is now scheduled to available capacity. This schedule is now automatically added to the existing work centre loading file. Any new orders will therefore have to be scheduled based on the latest loading condition which includes works order 103.

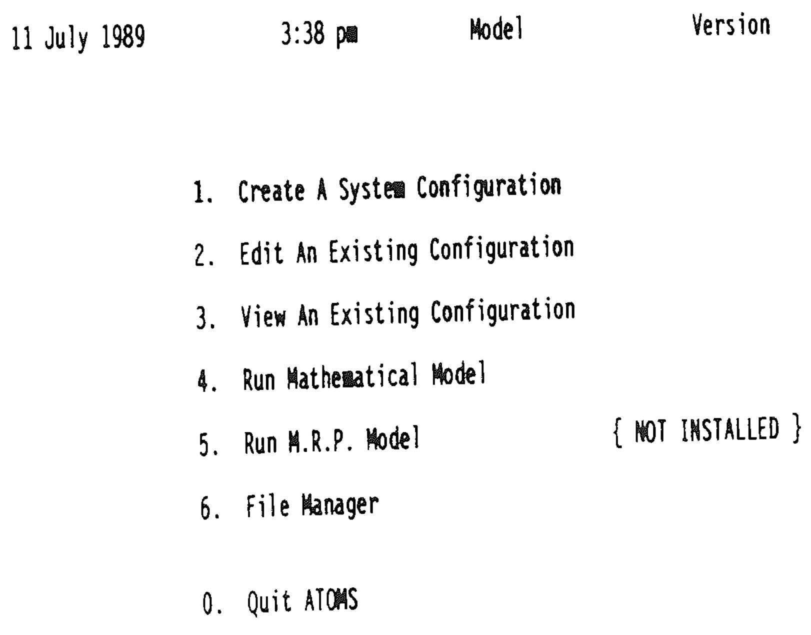
APPENDIX III AN OVERVIEW OF THE ATOMS SIMULATOR AND EXAMPLES OF MODEL DATA

This appendix will present an overview of the ATOMS simulator system, highlighting the main system menus, as well as examples of the model data which were used in the comparative simulation experiments discussed in chapters 9 and 10.

III.1 AN OVERVIEW OF THE ATOMS SIMULATOR

The ATOMS simulator was designed to be configurable across a range of manufacturing environments. The system can be configured by selecting specific options within each module.

Figure (III.1), shows the main system menu.



```
11 July 1989          3:38 pm        Model            Version


              1.  Create A System Configuration
              2.  Edit An Existing Configuration
              3.  View An Existing Configuration
              4.  Run Mathematical Model
              5.  Run M.R.P. Model            { NOT INSTALLED }
              6.  File Manager

              0.  Quit ATOMS
```

Figure (III.1)

Option 1 from the above menu, allows a factory model to be developed. Figure (III.2), shows the range of facilities which the system provides.

```
View  : 1.  Operator Groups

        2.  BreakDown Records

        3.  Work Centres

        4.  Work Centre Operations

        5.  Material

        6.  Transport Groups

        7.  Material Routing Data

        8.  Material Routing Operators

   Or : 0.  Quit
```

Figure (III.2)

Within each of the eight options there are a wide range of configurable options which allow both deterministic and stochastic models of manufacturing environments to be created. The model can then be executed using the range of facilities shown in Figure (III.3).

```
                 Period   1

Simulation : 1.  Parameters

             2.  Zero Model

             3.  Product Demand

             4.  Save Model

             5.  Execution

             6.  Results

         Or : 0.  Quit
```

Figure (III.3)

Section III.2 will provide examples of the features of the ATOMS which were utilised to develop the models for the simulation experiments described in chapters 8 and 9.

III.2 EXAMPLES OF ATOMS MODULES WHICH WERE USED IN THE SIMULATION EXPERIMENTS

To create a simulation model, option 1 from the main menu , figure (III.1) should be selected. From the next menu, figure (III.2), to create a deterministic model of a factory with three cells, options 1 and 2 are not required. Option 3 allows the creation of any number of work centres which are required. Figure (III.4), shows the three work centres which were created. In this case there were three assembly type work centres (type 4) and there was one work station per cell. The modelling level RoughCut, was used since the features such as Transport Groups and BreakDown Records (figure III.2) were not used.

```
NUMBER    WORK CENTRE     MODELLING     WORK CENTRE      NUMBER OF
              NAME           LEVEL          TYPE       WORK STATION(s)

  1             CELL1      RoughCut          4                1
  2             CELL2      RoughCut          4                1
  3             CELL3      RoughCut          4                1
```

Figure (III.4)

Option 4 allows the creations of the type of operations which would take place in each cell. Figure (III.5), shows that in cell 1, three products (ie, Modem-100, Modem-200 and Modem-300) are produced.

NUMBER	MATERIAL NAME	OPERATION NUMBER	SETUP TIME	STANDARD TIME	SCRAP %	TRANSFER QUANTITY
1	MODEM-100	1	60.0 F	5.0 F	0.00	
2	MODEM-200	1	60.0 F	5.0 F	0.00	
3	MODEM-300	1	60.0 F	15.0 F	0.00	

Figure (III.5)

Modem-100 has a setup time of 60 minutes and standard time (i.e., unit time) of 5 minutes. The letter F indicates that these times are deterministic.

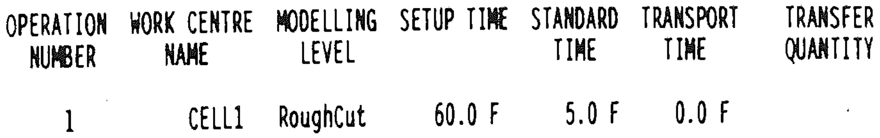
Option 5 allows the creation of bill of materials. For each product the lower level components can be specified as well as, the number units is stock. Figure (III.6), shows the range of parts for which bill of materials was created.

NUMBER	MATERIAL NAME	MATERIAL PART SCALE	MADEIN Or BUYOUT	PURCHASE LEADTIME (Days)	CURRENT STORE QTY
1	MODEM-100	1.0	MadeIn	0.0 F	0
2	MODEM-200	1.0	MadeIn	0.0 F	0
3	MODEM-300	1.0	MadeIn	0.0 F	0
4	CASE-100	1.0	MadeIn	0.0 F	0
5	CASE-200	1.0	MadeIn	0.0 F	0
6	CASE-300	1.0	MadeIn	0.0 F	0
7	PCB-100	1.0	MadeIn	0.0 F	0
8	PCB-200	1.0	MadeIn	0.0 F	0
9	PCB-300	1.0	MadeIn	0.0 F	0
10	COMP-100	1.0	BuyOut	0.0 F	100000
11	COMP-200	1.0	BuyOut	0.0 F	100000
12	COMP-300	1.0	BuyOut	0.0 F	100000

Figure (III.6)

The lead times for the products are specified by the MRP II system therefore the lead time facility of the model is not required. The works orders would be scheduled based on the MRP suggested start and due dates and will be shown in the works order file. The purchased items are the parts COMP-100, COMP-200 and COMP-300. The model was setup to have sufficient components for the whole of the simulation periods.

Option 6 was not used in the model. Option 7 allows the creation of routing data for each part. Figure (III.7), shows the routing data for Modem-100. Operation number 1 was specified earlier in option 4. The routing data will allow additional information to be added to the basic operation. In this case transport time and transfer quantities were not used.



OPERATION NUMBER	WORK CENTRE NAME	MODELLING LEVEL	SETUP TIME	STANDARD TIME	TRANSPORT TIME	TRANSFER QUANTITY
1	CELL1	RoughCut	60.0 F	5.0 F	0.0 F	

Figure (III.7)

Option 8 is useful for the creation of stochastic models. In this case the operator efficiency was set at 100%. Figure (III.8) shows that in operation 1 the operator efficiency was set at 100%.

```
OPERATION  MODELLING   SET UP      PROCESS   OPERATOR  TRANSPORT  TRANSPORT
 NUMBER      LEVEL    OPERATOR    OPERATOR  EFFICIENCY  OPERATOR    DEVICE

    1      RoughCut                           100.00
```

Figure (III.8)

Having created the above model then the simulation parameters can be specified. The model should be saved. The simulation runs can be executed, by typing EXECUTE after exiting the ATOMS.

Figure (III.9), show the EXECUTE menu.

```
1.  Run Simulation Model

2.  File Manager


0.  Quit ATOMS
```

Figure (III.9)

Option 1 allows the simulation parameters and product demand characteristics to be created. Figure (III.10), shows the simulation menu.

```
              Period  1


Simulation : 1.  Parameters

             2.  Product Demand

             3.  Save Simulation Parameters

             4.  Execution

             5.  Results


        Or : 0.  Quit
```

Figure (III.10)

Option 1 from this menu allows the simulation parameters to be to be determined. Figure (III.11), shows the parameters which can be selected. In this case the model is to be simulated under 8 hour per day, 5 working days per week for 1 period.

```
1. Length Of Working Shift (Hrs)    [ 8.00]

2. Length Of Working Period (Days)     [ 5]

3. Number Of Periods To Simulate      [  1]

4. Results Recorded After (Hrs)     [    0]

5. Write Daily Log To File,             [N]
         Printer Or NO Log (F\P\N)
```

Figure (III.11)

Option 2 from the simulation menu Figure (III.10), allows the product demand characteristics to be created. Figure (III.12), shows the range of options available.

```
Order Demand : 1. Enter Data

               2. Part Probability

               3. Create Orders

               4. View Orders

               5. New Sale File

               6. Save


               0. Quit
```

Figure (III.12)

Option 1 from this menu allows the demand characteristics of each product to be created. Figure (III.13), shows the demand data for product Modem-100.

```
Part Name Or Code Number [ MODEM-100]

     Random Stream [ 1]

     Random Seed [   0.0]           Random Multiplier [         0]


          A:  [  30.0]                    B:  [   0.0]

          C:  [   0.0]                    D:  [   0.0]

          E:  [   0.0]                    F:  [   0.0]

          G:  [   0.0]                    H:  [   0.0]

          U:  [   0.0]                    AK:  [   5.0]
```

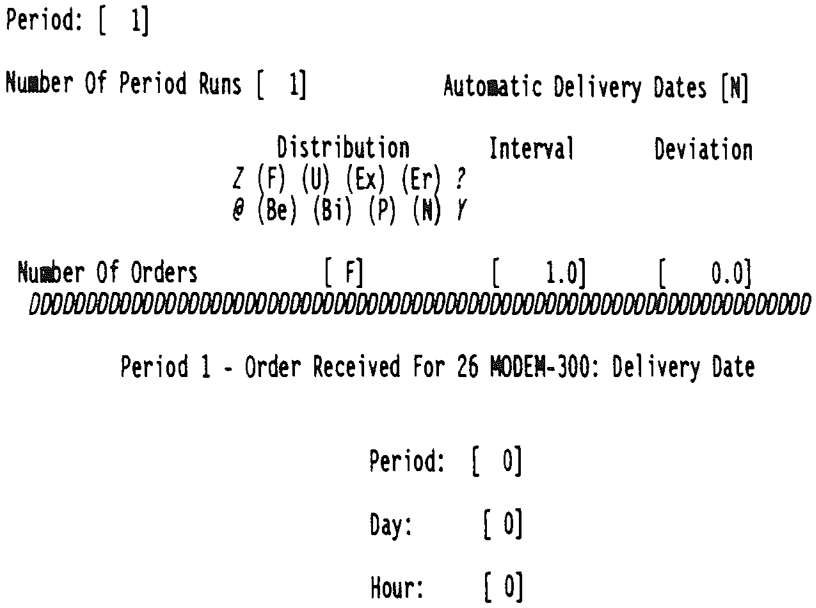
Figure (III.13)

The letters A to AK allow various forms of demand including demand patterns with seasonality to be created. In this case the product had a mean of 30 units and a standard deviation of 5 units. The random seed 1 with a seed of 0.0 was selected for all three modems. Option 2 From the same menu allows the creation of part probability. In this case each of the three modems had equal probability of being selected. Figure (III.14), shows that each product has an interval of 100. This implies equal probability. The system adds up the intervals and assigns the appropriate probability to each product. The probability of each part being selected therefore is 0.33333 > .

```
  Part Name Or Code Number   Prob. Distribution   Interval    Deviation
                             Z (F) (U) (Ex) (Er) ?
                             @ (Be) (Bi) (P) (N) Y

3.      [ MODEM-300]               [ F]          [ 100.0]   [     0.0]
2.      [ MODEM-200]               [ F]          [ 100.0]   [     0.0]
1.      [ MODEM-100]               [ F]          [ 100.0]   [     0.0]
```

Figure (III.14)

Option 3 from the simulation demand menu figure (III.12), allows the automatic creation of sales orders. Figure (III.15), shows an example of an order being generated.



```
Period: [  1]

Number Of Period Runs [  1]           Automatic Delivery Dates [N]

                         Distribution      Interval       Deviation
                     Z (F) (U) (Ex) (Er) ?
                     @ (Be) (Bi) (P) (N) Y

 Number Of Orders           [ F]              [    1.0]       [    0.0]
  DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD

          Period 1 - Order Received For 26 MODEM-300: Delivery Date

                            Period:  [  0]

                            Day:      [ 0]

                            Hour:     [ 0]
```

Figure (III.15)

In this case the interval was set at 1 which means only one order should be generated. The system can automatically assign a lead time for each product. But the MRP system was used to determine the product lead times for the simulation experiments. In this example the delivery date was set for period 5, day 1 and hour 9. Figure (III.16), show the the delivery date.

```
Period: [  1]

Number Of Period Runs [  1]          Automatic Delivery Dates [N]

                         Distribution       Interval       Deviation
                       Z (F) (U) (Ex) (Er) ?
                       @ (Be) (Bi) (P) (N) Y

 Number Of Orders            [ F]            [    1.0]       [    0.0]
 DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD

          Period 1 - Order Received For 26 MODEM-300: Delivery Date

                              Period:  [  5]

                              Day:      [ 1]

                              Hour:     [ 9]
```

Figure (III.16)

As it was stated in chapter 9, the product demands were rounded to the nearest 5 to simplify the data handling and to minimise data input errors. This was achieved by editing the sales order file using word processor (Word Star). The sales orders were then input into the UNIPLAN MRP II system to determine their manufacturing lead times and the customer due dates. This information was then input into the sales order file. The order generation was setup to produce 7 orders per period. Figure (III.17) shows a segment of the sales order file after the above procedure had been carried out.

Order No.	Period	Day	Hour	Material Number	Quantity
331	49	2	9	MODEM-200	40
332	49	3	9	MODEM-300	35
333	49	4	9	MODEM-200	20
334	49	4	9	MODEM-100	30
335	49	5	9	MODEM-300	30
336	50	1	9	MODEM-100	35
337	50	1	9	MODEM-100	25
338	50	1	9	MODEM-200	25
339	50	2	9	MODEM-100	30
340	50	2	9	MODEM-100	30

Figure (III.17)

The works order file was created automatically using the UNIPLAN MRP II system and the Desqview software. The works order start and end dated were translated into period numbers and day numbers to comply with ATOMS data format. Figure (III.18), shows a segment of the works order file . The first column is the works order number, second column is the period number when the job is scheduled to start and the subsequent two columns refer to the day

```
Wo 50 4 9 51 5 9      25.0000 CASE-100 1
Wo 51 5 9 53 1 9      25.0000 MODEM-100 1
Wo 49 1 9 50 4 9      25.0000 PCB-200 1
Wo 50 4 9 52 1 9      25.0000 CASE-200 1
Wo 52 1 9 53 1 9      25.0000 MODEM-200 1
Wo 49 1 9 50 4 9      30.0000 PCB-100 1
Wo 50 4 9 51 5 9      30.0000 CASE-100 1
Wo 51 5 9 53 1 9      30.0000 MODEM-100 1
Wo 49 1 9 50 4 9      30.0000 PCB-100 1
Wo 50 4 9 51 5 9      30.0000 CASE-100 1
Wo 51 5 9 53 1 9      30.0000 MODEM-100 1
Wo 49 1 9 50 4 9      30.0000 PCB-100 1
Wo 50 4 9 51 5 9      30.0000 CASE-100 1
Wo 51 5 9 53 1 9      30.0000 MODEM-100 1
Wo 49 1 9 50 5 9      35.0000 PCB-300 1
Wo 50 5 9 52 1 9      35.0000 CASE-300 1
Wo 52 1 9 53 1 9      35.0000 MODEM-300 1
Wo 49 1 9 50 4 9      35.0000 PCB-200 1
Wo 50 4 9 52 1 9      35.0000 CASE-200 1
Wo 52 1 9 53 1 9      35.0000 MODEM-200 1
```

Figure (III.18)

and hour when the job is scheduled to start. The fifth, sixth and seventh columns are the period, day and hour when the the job is due to be delivered. The eighths column is the batch quantity and the ninth column is the product code.

Once all the relevant data is in place option 3 of the main simulation menu, Figure (III.10), allows the whole model to be saved, ready for simulation execution.

Option 4 from the main simulation menu allows the executions of simulation runs based on the parameters selected earlier (figure (III.11)).

Option 5 from the main simulation menu allows the results of the simulation runs to be accessed. Figure (III.19), shows the range of options available.

```
Results For : 1.  Work Centres

              2.  Stores

              3.  Transport

              4.  Operators

              5.  Tooling

              6.  Completed Orders

              7.  Everything

         Or : 0.  Quit
```

Figure (III.19)

Figure (III.20), shows summary report from ATOMS at period zero and figure (III.21) shows the same report after four periods of simulation runs.

```
Total Material Action
=====================

Material     On     Due  Issued  Recieved  Scrap  Sold    Sold  Back    Ave Flow
            Hand    In                            OnTime  Late  Orders  Time(Hr)

MODEM-100       0    0      0        0       0      0      0      0      0.00
MODEM-200       0    0      0        0       0      0      0      0      0.00
MODEM-300       0    0      0        0       0      0      0      0      0.00
 CASE-100       0    0      0        0       0      0      0      0      0.00
 CASE-200       0    0      0        0       0      0      0      0      0.00
 CASE-300       0    0      0        0       0      0      0      0      0.00
  PCB-100       0    0      0        0       0      0      0      0      0.00
  PCB-200       0    0      0        0       0      0      0      0      0.00
  PCB-300       0    0      0        0       0      0      0      0      0.00
 COMP-100  100000    0      0        0       0      0      0      0      0.00
 COMP-200  100000    0      0        0       0      0      0      0      0.00
 COMP-300  100000    0      0        0       0      0      0      0      0.00
```

Figure (III.20)

```
Total Material Action
=====================

Material     On     Due  Issued  Recieved  Scrap  Sold    Sold  Back    Ave Flow
            Hand    In                            OnTime  Late  Orders  Time(Hr)

MODEM-100      30    0      0      280       0    250      0      0      6.63
MODEM-200       0    0      0      190       0    190      0      0      4.63
MODEM-300       0    0      0      170       0    170      0      0     26.60
 CASE-100      30    0    280      310       0      0      0      0      6.20
 CASE-200       0    0    190      190       0      0      0      0     24.33
 CASE-300      25    0    170      195       0      0      0      0     14.54
  PCB-100       0    0    310      310       0      0      0      0     25.55
  PCB-200      35   30    190      225       0      0      0      0     14.76
  PCB-300      30    0    195      225       0      0      0      0     16.69
 COMP-100   99690    0    310        0       0      0      0      0      0.00
 COMP-200   99745    0    255        0       0      0      0      0      0.00
 COMP-300   99775    0    225        0       0      0      0      0      0.00
```

Figure (III.21)

As well as the summary report above, the system provides more detailed data about each works order and work centre operations. The above is a sample of the type of data which ATOMS produces. The more detailed data regarding the individual works orders and

WIP levels, at the time using the model, were presented in the form of large data files from which specific data was manually extracted. The system has since been improved to allow easier extraction of detailed data.

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