PRODUCTION PLANNING AND CONTROL : AN INVESTIGATION

by

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A Master's Thesis submitted for the award of

Master of Philosophy Degree

of the Loughborough University of Technology

January 1983

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ACKNOWLEDGEMENTS

To Professor Gregory for his advice and encouragement

To the Management of John Davis and Son (Derby) Ltd. for allowing this project

To David Bonser, Production Planning Manager and his Staff for their assistance

To Barbara Ruane for the expert typing of this thesis

To Jean Roberts and colleagues in the Computing Division of Derby Lonsdale College of Higher Education, for help and advice.

A B S T R A C T

The objective of this research is to identify how production planning and control theory may be successfully applied in a practical situation.

The thesis is presented in two distinct parts; Part I representing a survey of literature concerned with theory and research findings on production planning and control. Part II focuses on the development of selected material from the literature survey and the application of the product to an actual industrial situation where the appropriateness is tested.

The majority of order quantity techniques involve some economic criteria in their formulation. This criteria has been discounted and an empirical lot size is selected which results in an acceptable level of disruption to a given master production schedule.

A time phased order point technique is used, employing an item's demand forecast directly as a given requirement creating a master production schedule for an item experiencing independent demand. To reduce the 'nervousness' of the system, the lot size is held constant throughout the planning period and adjustments made to the replenishment timing to accommodate any major discrepancy between the master production schedule and the actual customer requirements.

The model basically applies the 'management by exception' rule to production planning and control, where management plan and provide resources in detail to meet future requirements. To prevent over-reacting to unplanned occurrences, management will only take additional action when activities extend beyond set control limits

with provision made for re-setting the control limits should any new trend in demand be recognised.

It is concluded that the model developed will allow a stable production plan to be effectively used to meet the random volatile demand for a product with minimal disruption to the plan. The disruption, however, can be readily accommodated with the use of existing resources available to the company.

PART I

CHAPTER I

INTRODUCTION

1.1 Objectives of Production Control

Universally acceptable objectives of Production Control are difficult to formulate; they depend on the type of product, market and plant which collectively influence the objectives of production control. A minimum requirement of production control will be :

> "The co-ordination of the production facilities to produce a product at an optimal cost."

A more extensive objective of production control is given in the Dictionary of Production and Inventory Control Terms :

> "Production Control is the function of directing the orderly movement of goods through the entire manufacturing cycle from the requisitioning of raw materials to the delivery of the finished product, to meet the objectives of customer service, minimum inventory investment, and maximum manufacturing efficiency."

It is not uncommon to find production control compared to the nervous system of the human body; this is a realistic comparison for, as the human body responds to the nervous system, so does the whole manufacturing system respond to production control through a comprehensive communications network. The nerve system assures conformance by many feedback links, as does the production control system.

Regulation of the system network by the feedback of information produced in the system is the core of cybernetics. The term cybernetics is derived from the Greek word 'kybernetes', meaning pilot or steersman. The term was coined by Norbert Weiner and developed in his book by the same name published in 1949 [70]. The subtitle of the book "Control and Communication in the Animal and Machine", serves generally to indicate the nature of his study. Cybernetics concerns itself with the way in which human beings reach decisions and control various functions and operations. It then seeks to structure these decision procedures in such a way that they can be duplicated by machines, usually the electronic data processing machines, or computers.

Synergetics and Symbiosis are both concepts, presently of considerable utility in other scientific disciplines, which show promise of useful application to the problems of Management Science.

Synergism refers to the joint action of agents which, taken together, increase each other's effectiveness. When related to a manufacturing concern it implies that the judicious combination of men with men, or men with machines, or one department with another, will often yield a potential far exceeding that of the separate components.

The term symbosis, drawn from the natural sciences, refers to the living together of two dissimilar organisms, especially when the association is mutually beneficial. Depending upon the way the dissimilar organisms are defined, there can be many examples of this felicitous relationship not only among feathered, furred and finny creatures, but also among areas of present business enterprise. Not the least of these is suggested the man-computer accommodation so necessary to optimise performance by large organisations functioning in a complex society.

1.2 Responsibilities of Production Control

Production Planning will be considered an integral part of the production control function; if a distinction is to be made between planning and control it is that the planning function establishes the requirements whilst the control function is concerned with keeping the activities within these requirements.

The noted inventory consultant Oliver Wight divides production control into two essential problem areas : Priorities and Capacity. Priorities refer to what material is needed and when it is needed, and capacity refers to how much human and/or machine time is needed to transfer the material to a finished good. Since inventories are the quantities of materials that must be made available in the appropriate time schedule, it is perhaps obvious that the inventory control and scheduling activities of production control management are thoroughly inter-dependent.

It must be accepted that different responsibilities of production control will be indentified in different organisations; a list of responsibilities which might be included in a production control department would be :

Receive and record orders from sales
Estimate the cost of new jobs
Liaise between the factory and sales
Forecast sales
Issue Purchase requisitions
Make decisions to make or buy
Maintain control over raw materials and finished goods
Establish inventory levels
Determine routing of purchased material
Determine routing of finished goods
Determine internal transportation of material
Estimate manpower and machine requirements

Make schedules and maintain production throughout the plant
Replan schedules
Assign jobs to men and machines
Despatch production orders
Expedite orders
Evaluate performance
Design and redesign data processing systems
Data processing
Install data processing systems
Program computers
Evaluate data processing systems.

1.3 Conflicting Roles of Production Control

It has been established that the prime objectives of Production Control are :

1) Orderly movement of goods throughout the manufacturing cycle.
2) Requisition of raw materials.
3) Delivery of finished goods to customers on time.
4) Keeping a minimum investment in inventory.
5) Maximising the efficient use of the manufacturing facility.

If financial resources were not limited, the production control function would be relatively simple, but production control is competing for financial resources within the organisation, consequently the differing needs of sales, manufacturing and inventory have to be balanced to maximise the collective benefits of the limited resources available. Production control must co-ordinate the production facilities and this can only be achieved by linking communications between the inter-dependent and intra-dependent parts of the system. Processes such as communications, decision-making and balance are necessary for a basic interaction to take place which sustains the life of the organisation. Deutsch [21] points out, communication allows the parts of the organisation to 'talk' to each other; it brings in information from the outside, and it provides the means for storing and retrieving information within the system.

The separate parts of the organisation have a commonality of interest in making a product on schedule at an optimum cost, but the method of achieving this is, at times, a source of disagreement. The sales department is interested in sales; this can be accomplished only if the customer is satisfied and he is usually satisfied if he obtains a product of the quality he desires at a reasonable cost and on time. Usually the delivery date becomes the point of conflict between production control and the sales department. To the sales personnel the delivery date is more important than producing within a budget because a record of poor delivery can damage customer relations, with the resultant loss of customers.

The purchasing personnel require requisitions placed well in advance of the time the material is needed and to be able to purchase all materials in economic quantities and to have the freedom to substitute whenever this is desired.

Engineering would like to have designs accepted by the factory, regardless of the manufacturing difficulties; it would also like to instigate design changes instantaneously.

Quality control are concerned with meeting the product standards, regardless of the production schedules to be met.

The personnel department would like to maintain a constant labour force and supply skills from the available pool of labour. They would also like to have forecasts of future labour requirements in order that they can train or attract the people to fulfil the requirements.

Factory management is interested in long production runs with infrequent changes. They would like to keep inventories low, but at the same time have sufficient inventory available to keep the factory busy. It is amongst all these conflicting objectives that production control must operate and a successful outcome is only possible when the interests are balanced to enable the overall objectives of the organisation to be achieved.

The areas of conflict have attracted the efforts of interested bodies who have made provisions to overcome the harmful effects of their divisions. Co-ordination of the activities may be achieved if the organisation structure is designed to facilitate this. One approach outlined in a paper presented by members of the Board of Management of the Institution of Purchasing commented that "a further significant measure of development must be applied nowadays in the general management field : the rationalisation of functions common to related disciplines. This is not simply a result of basic economic studies; it has emerged by natural evolution in many organisations where activities common to several functional departments have been concentrated in a separate department, with the general effect of co-ordinating the total range of activities in meeting the total objective." [56] The Purchasing Institution recommended the following definition : "Materials Management is the total of all these tasks, functions, activities and routines which concern the transfer of external materials and services into the organisation and the administration of the same until they are consumed or used in the process of production, operations or sale."

Materials management offers some solid benefits as a type of organisation but, unfortunately, it is not the cure-all that some expect it to be. This organisation structure does not permit the use of systems, procedures, or techniques for controlling, that cannot be used without it. The principle benefit to be derived from this form of organisation, in which all the people concerned with the flow of material through the plant report to one man, is that he can direct activities to get the most co-operation and effectiveness from these people working together. If the only way to get the managers responsible for materials handling, traffic, purchasing and production control to work together effectively, is to have them report to the same boss, then the materials management concept offers real potential benefits. In companies that have grown so large that the span of control is unwieldy for the top level managers, to whom the purchasing manager, production control manager, traffic manager, warehouse manager, etc., report, a materials manager is undoubtedly justified.

Management literature in the mid 1960's introduced the term "operations management". Wild [75] offers two reasons for this development. One reason is that much of what was used to be discussed under the title of production management was of little relevance in non-manufacturing systems, and therefore, there is some justification in considering, under one heading and as one subject, the management of manufacturing and non-manufacturing systems. Secondly, in the 1960's production management, whilst being recognised as being of considerable importance, had attracted little interest in academic circles. It was convenient, therefore, to encourage this subject to 'expand' with the prospect of its developing as a more attractive field for study. Wild says that, although operations management has become established in the past decade, it has to a large extent failed precisely where production management failed. The operations manager is seen as a key central figure in management but in too many cases he, and his function, is inadequately represented at a policy level in the organisation.

The operation management concept is concerned with an increase in the areas of responsibility outlined in both the Production Control and Materials Management approaches. The involvement in Strategy and Policy Making activities is a justifiable concern of operations management. Policy and Strategy have direct and indirect implications for the Production Manager. Ansoff [1] considers that the operating decisions usually absorb the bulk of the firm's energy and attention. The major decision areas are resource allocation among functional areas and product lines, scheduling of operations, supervision of performance, and applying control actions. The key decisions involve pricing, establishing marketing strategy, setting production schedules and inventory levels, and deciding on relative expenditure in support of research and development, marketing and operations. Strategic decisions assure that the firm's products and markets are well chosen, that adequate demand exists, and that the firm is capable of capturing a share of the market. Strategy imposes operating requirements : price-cost decisions, timing of output to meet demand, responsiveness to changes in customer needs and technological and process characteristics. The administrative structure must provide the climate for meeting the operating requirements. The structure is formulated by the Strategy, the product-market characteristics create operating needs, and these in turn determine the structure of authority, responsibility, work flows, and information flows within the firm. Sloan [61] in his memoirs, diagnosed one of the major requirements which strategy has imposed on structure : "to organise the firm's management in a way which assures a proper balance of attention between the strategic and operating decisions".

Plossl and Wight [55], in their views on the future of production control, state "The new organisational forms that will develop as a result of the current revolution in information management are difficult to predict to-day, but there is no question that traditional organisational forms are going to change drastically and that the 'production control' department, as we know it, may disappear. The title of the function is really of secondary importance - no matter what it is called, the basic information required to manage a manufacturing operation in the face of intensive competition will become more and more vital to every company. This planning and control function will not only become more important in the operation of the company, but will become a vital training area as well. A background in systems, particularly manufacturing control systems, will undoubtedly be one of the requisites for top managers of the future".

CHAPTER II

THE EVOLUTION OF PRODUCTION AND INVENTORY CONTROL

2.1 Development of Production Control

Production Control and Inventory Control developed separately. Production control was one of the functions carried out by the early foreman. He ordered material, controlled the size of the workforce and level of production by hiring and firing people, expediting work through his department and controlling customer service through the inventories that resulted from his efforts. As the foreman's workload increased, he was assisted by a clerk who would take care of timekeeping, keeping records and answering the telephone in his department. These functions brought the clerk into frequent contact with the Sales Department while answering requests for the status of jobs and for delivery promises; he also began re-ordering materials and planning other preparations needed for production, in addition to following progress of work. He was really the beginning of the production control function.

The increase in demand resulted with the increase in the activity of the clerk and the record keeping duty was transferred into the main office, the clerk's main role was that of Stock Chaser. One prominent New England company in the 1890's had a department known as the 'Hurry-up-Department' which might be applicable today if an organisation does not adopt a responsible approach to the production control function.

One of the earliest documented production control systems was installed at the Watertown Arsenal in the 1880's [60] but general application did not develop prior to World War II.

By World War II, the position of stock chaser had fallen into disrepute; the worker associated him with crises, upsets, pressures and trouble. Henry Kaiser gave his Shipbuilding company stock chasers the name of 'expediters' and, with the help of a Readers Digest article, popularised the concept of the expediter as an action orientated go-getter who made a vital contribution to meeting production schedules. By the 1950's the term 'expediting' was often used in books defining production control; the activities associated with the expediter were ordering the necessary parts to make an assembly after receiving the customer's order, following the order through manufacture, and, if delayed, putting a 'Rush' tag on them. Even today the expediter is an integral part of most production control systems. However, the efficiency of the system could be measured using an inverse factor of the number of expediters employed.

Inventory control, on the other hand developed, at least in theory, along more scientific lines. The basic concept of the economic lot size was first published in 1915 [35] and the statistical approach to determine order points was presented by R.H. Wilson in 1934 [76]. However, these fairly sophisticated techniques of inventory management found little application, the name of the game in the 1930's and 1940's was survival; the depression did nothing to encourage scientific management.

During the late 1940's, customer demand for products could not be satisfied, resulting in a ready market for every article produced. The objectives of inventory control - levelling workload or competing on the basis of customer service - were not important. It was not until markets became saturated that interests other than 'mass production' and 'lowest price of product' were considered. Even Henry Ford had to respond to the market and change his often quoted phase of 'Give it to them in any colour so long as it is black'.

In the early 1930's General Motors triggered a shift from production to a market focus. The introduction of the annual model change was symbolic of a shift in emphasis from standard to differentiated products. By contrast with the earlier 'production orientation' the new secret to success was by way of 'market orientation'. Henry Ford, having tried to replace a Standard Model 'T' with a Standard Model 'A', was forced to follow the multi-model package of General Motors.

The shift to the marketing orientation meant a shift from an internally focused, introverted perspective to an open extroverted one. It also meant a transfer in power from production-minded to market-minded managers. Consumer industries and technologically intensive producer industries were early in accepting the marketing orientation, whilst in the process industries and producer durable industries, the marketing concept was slow to penetrate.

Out of World War II came operations research - the application of scientific techniques to solving the problems of war, where the allocation of limited resources was a matter of victory or defeat. These operations research techniques were quite effective in World War II [57]. When the scientists connected with this work got back to the problems of a peacetime world, their attention focused on production and inventory control, where elements of the problem can be expressed numerically, where statistical probability theories can be applied and where so many of the decisions are the result of balancing alternative solutions. Some notable results were produced in forecasting, inventory control and mathematical programming, and whilst operations research has not solved all the business problems it set out to solve, it has generated a new interest in a more rational approach to production and inventory control.

Probably the biggest problem in applying scientific techniques in industry has been the fact that companies were not ready for these techniques because they had not even begun to solve many of their basic problems in controlling manufacture. Many companies did not even have accurate lists of the parts that made up their products or route sheets to list the operation sequences; they depended instead upon the memories of the men in the factory who had made the product for years. Before scientific techniques could be applied, basic information had to be readily available and accurate. In addition, the volume of calculations required for applying such techniques as the statistical determination of order points, which were highly developed by operations research, was considerably beyond the capabilities of manual systems.

From the mid 1950's, accelerating and cumulating events began to change the boundaries, the structure and the dynamics of the business environment. Firms were increasingly confronted with novel, unexpected challenges which were so far reaching that Peter Drucker called the new era an 'Age of Discontinuity' [22]. Alvin Toffler's book published in 1970 called 'Future Shock' had a wide appeal because of its dramatisation of technological change [65].

Toffler's hypothesis is that change is upon us so fast that we are personally and organisationally unable to adapt to it or cope with it. A view presented in the book by a management consultant, Bernard Muller-Thym, considers that the new technology, combined with advanced management techniques, creates a totally new situation. "What is within our grasp is a kind of productive capability that is alive with intelligence, alive with information, so that at its maximum it is completely flexible; one could completely re-organise the plant from hour to hour if one wished to do so".

By the late 1950's the electronic computer was being widely used in industry, but, as with most new technologies, there were as many failures as successes in applying this powerful tool. All the information processed had to be accurate, since the personal interference that even a good clerk could give was no longer available to correct obviously ridiculous errors and compensate for missing information. While the computer offered almost unlimited capacity in computation, it focused attention on the need for disciplines in information handling that many companies had failed to develop in the past. Efforts to apply the computer were often attempts to install a mechanical system in companies that had never taken manual systems seriously enough to make them work satisfactorily and these efforts were doomed from the very start. The restrictions of the earlier analog-type computer limited the practical application of the computer, the upper capacity of such machines barely overlapped the minimum size and complexity that was required to deal with non-linear problems. The appearance of the high speed electronic digital computer removed the practical computational barrier. The technical performance of electronic computers increased by a factor of nearly 10 per year over the decade of the 1950's [28], in almost every year there was a ten fold increase in speed, memory capacity or reliability.

Today, with the introduction of the silicon chip we can recognise a further rapid increase in computational power widening the gap even more between the technology and its industrial application. We have a tremendous untapped backlog of potential devices and applications; the availability of relative low cost computers removes the earlier barriers preventing their wide application in industry and organisations of all sizes. Companies need to take up the challenge and harness this computational power to improve their overall efficiency and remain competitive in the world market.

The foregoing outlines the changing demands on Production Control. The current picture is one of marketing change; if Toffler's predictions are true the rapid changes in the market will present a formidable challenge to management, and only the organisations capable of reacting to the challenge will survive. The computer will play a major role in supplying the information in time to enable decisions to be made, or alternatively, the computer will make decisions and implement these as part of the production system.

CHAPTER III

PLANNING OF WORK SEQUENCE

3.1 Scheduling and Loading

Scheduling and loading are two planning processes used in production control. Both are processes designed to assist in the efficient and systematic planning of work sequence. Scheduling is mainly concerned with finding the optimum starting and finishing times for each task in relation to attainment of a plan, whereas loading is concerned with the efficient utilisation of capacity and the determination of reliable delivery promise dates.

There will be, by necessity, a certain amount of overlap between the two activities. Scheduling prescribes where and when each operation shall be performed, also at the same time 'loads' the work centres concerned. The main difference between scheduling and loading is one of intention. When engaged in planning the order and sequence of work with the view to completing it by a given due date, the operation is called scheduling. When attempting to compare load and capacity to determine if there is sufficient capacity available for a given programme or if there is spare capacity which can be used for other work, the operation is called loading.

The success of scheduling and the eventual loading of a product in a manufacturing situation is largely dependent upon the long term strategic plan which is prepared by senior management. The strategic plan commits the company to a configuration of manpower, skills, plant and equipment. Because the plan can require a substantial amount of capital in its realisation, it needs to be approved well in advance of the need of the resources in question. This time delay can result in a constraint of actual resource requirements identified closer to the production date.

In the very short term, control involves putting men in the right places, working on the right jobs and regulating production and inventory levels. To enable the short term plans to be realistic it is necessary for the longer term strategic plan not to unduly restrict decision making at the lower level. Flexibility to react to new information and deviations from high level plans must be built into the system at all levels. Feedback information on actual conditions and performance must flow upwards through the system to ensure that long range plans are based on a realistic assessment of the production organisation ability to produce. Such information flow and planning must be an on-going process to be successful.

Scheduling and loading can be carried out in two distinct ways -

(1) INFINITE LOADING which is usually based on backward scheduling which tends to minimise work in-process. With backward scheduling the planner starts with the 'date wanted' on the requisition and works backwards to the required starting date. This is achieved by deducting the cumulative lead times of operations in series from the date wanted, thereby establishing the start time for each operation in the work centre. Updating an infinite load is relatively simple; completed jobs are removed and new jobs added as they are released.

    If the required starting date is in the past, which would result if there is insufficient time to manufacture the article in the lead time allowed, then the planner must use forward scheduling to arrive at a realistic planned completion date. An alternative decision to this could be to manufacture the article in less than allowed lead time but this should be the exception rather than the rule.

(2) FINITE LOADING: this approach is not simple and requires considerably more effort than Infinite Loading. It starts with a schedule of work orders determined in the same way as for infinite loading. Before finite loading can commence, however, priorities must be set on individual orders. Obviously, the highest priority orders should get first claim on available capacity in each work centre. The next step is to set limiting capacities for each work centre. This is usually done with two values - 'Standard' capacity and 'Maximum' capacity, the latter including overtime or an added shift. The jobs are then loaded into the individual work centres in priority sequence. As soon as the work centre is filled to its limiting capacity, additional jobs are re-scheduled, either earlier or later, until they find available capacity. Because the requirement to load is based on capacity, a finite load cannot be up-dated using the add and deduct approach as with infinite loading. The only way to revise the finite load is to start again, re-arranging jobs in the new priority sequence and reloading.

Wight [53] states that 'loading should commence on the infinite load basis; this will show what capacity is needed, whereas finite loading will not. It assumes the capacity is absolutely inflexible. The result of finite loading is predictable. Some orders will not be completed on time and the master schedule will have to be changed. Capacity requirement planning will quickly identify a capacity requirement that cannot be met, with a resulting change in the master schedule without the sophistication of having to go through the finite loading procedure.

Capacity requirement planning does not try to plan based on an accumulation of backlogs, but instead works from a forecast of capacity requirements based not only on released orders but also on the planned orders that would show in a material requirements plan, or in the time phased order point system. The plan will indicate when serious under- or over-loads are going to develop before they happen. This provides management with the ability and the time to plan alternative courses of action, such as sub-contracting, expediting or re-scheduling to smooth loads, using overtime, or possibly, revising the master schedule.

This practical approach to scheduling and loading is due mainly to the inability of a mathematical solution being realistic of the situation. Knowing the inputs to the system, such as firm customer orders, forecasted demand, inventory status and production capacity, it would seem ideal to establish a master production schedule that minimises total relevant costs, while staying within the capacity constraints. However, the relevant costs are not restricted to those at the master level. The complicated nature of a manufacturing environment rules out cost minimisation. Instead, one strives for a feasible master schedule that appears to keep costs at a reasonable level.

3.2 Forecasting

In order to maintain a smooth flow of work in the production shops and to ensure that the product demand is met, the management of most manufacturing companies have to make estimates of future product demand.

These estimates might be based on an educated guess, close liaison with the customers, the use of mathematical models or a combination of all three.

Plossl and Wight [55] consider it ironic that forecasts made by marketing or sales departments often have greater effects on customer service than any other manufacturing activity. Forecasts, while they can definitely be improved, will always be wrong. The goal of progressive companies is to improve their forecasting and simultaneously, to develop sound, flexible production control systems based on forecasting principles and characteristics.

Forecasting future events will be less accurate as the period covered by the forecast increases. The duration of the forecast for inventory requirements is governed by the lead times of items used in the final product. The forecasting of individual items at all levels of manufacture is discussed elsewhere in the thesis, the outcome being that dependent items should not be forecast, only independent ones. However, this principle requires that the minimum forecast period for the product will be the duration of the cumulative lead times of all items manufactured and assembled in sequence. It is not unknown for cumulative lead times to be in excess of twelve months, i.e. time elapsed between ordering raw materials and the completion of the product. In such instances, a twelve month forecast of customer needs will not be reliable. Any adaptive forecasting technique such as the tracking signal method developed by Trigg and Leach [67] will filter out small random variations in demand, allowing the tracking signal to detect sudden changes and with the use of a computer, automatically up-date the forecast.

If adaptive forecasting is applied to the inventory system outlined above, the long lead time will negate the advantages of forecast modification. The information will arrive too late to influence decisions already made and acted on.

In most organisations the customer demand fluctuates and it is extremely difficult, if not impossible, to predict correctly the future level of demand. However, the calculation of the forecast error in itself helps to maintain a correct level of safety stock over a period, and, therefore, cushion the effect of variations in the demand level.

Orlicky [49] states that the time-phased order point used with material requirements planning, has the ability to replan and to keep replanning quickly, accurately, and automatically. This ability to replan is effective whether the need is caused by a change in the forecast or a disparity between actual forecast and demand. The self adjusting capability of the technique makes the relative forecast accuracy almost unimportant.

Working with poor forecasts is still the order of the day, and will likely continue to be. If so, refinements in forecasting techniques are a lot less important than the development of planning methods that enhance the ability to live with poor forecasts.

One might consider that, should the production forecast be optimistic hence supplying goods in excess of normal customer demand, the onus is then on the sales department to actively sell these goods using any or all of the sales techniques at its disposal.

3.3 Master Production Schedule

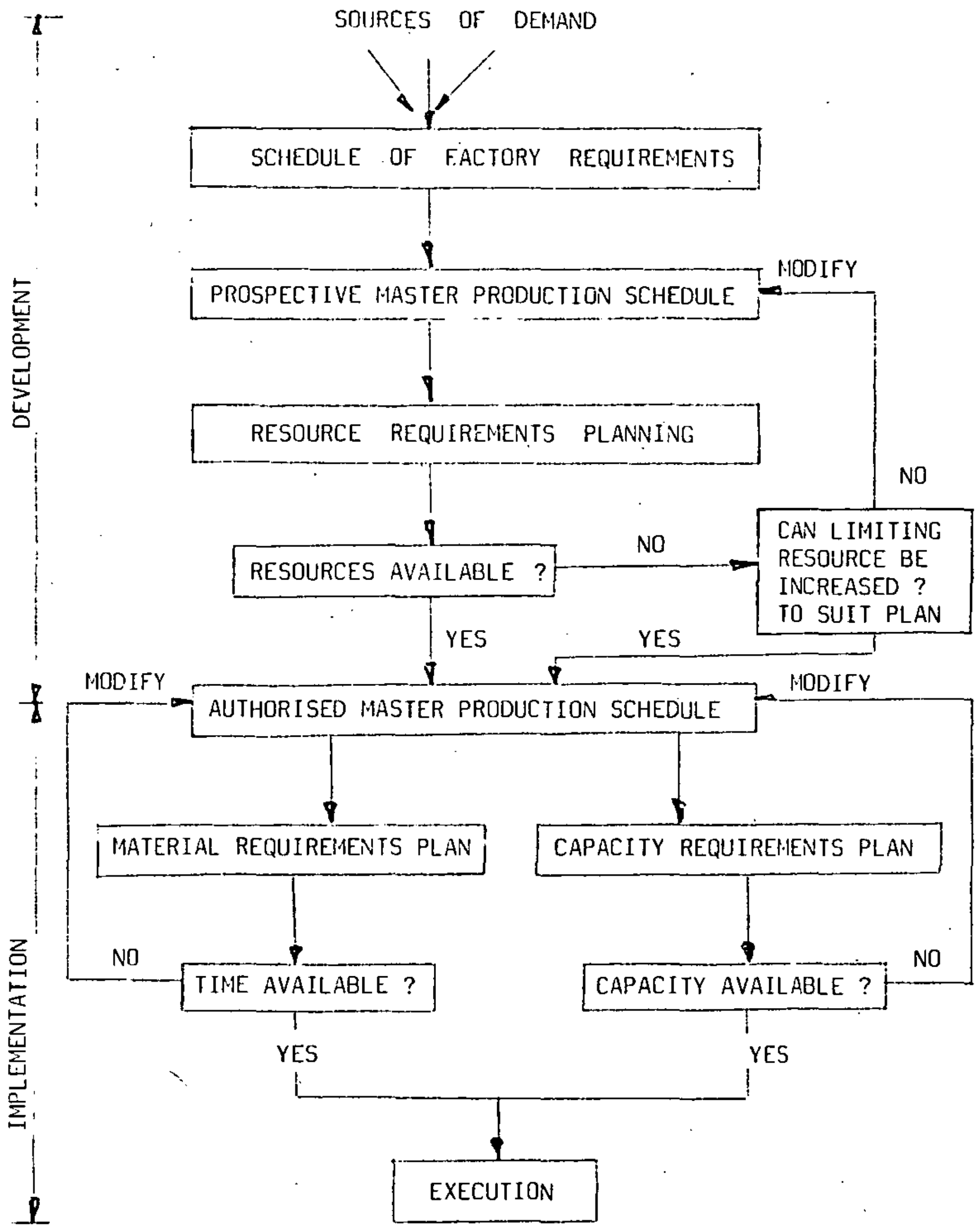
Plossl [52] states that it is becoming more widely recognised that better planning and scheduling can improve customer service, reduce capital invested and increase productivity simultaneously; nothing else has the ability to do this. The basic elements required in a control system which are necessary to achieve the above conditions are :

1) The Master Production Schedule - which translates marketing forecasts into specific quantities of individual products to be made in various time periods over the short and intermediate time period. Over the longer time period more general information such as data on typical products or totals for families of products can be used in the master production schedule to develop capacity requirements and capital needs.

2) Plan and Control Capacity - this determines the manpower and equipment requirements needed to meet the master production schedule, measuring actual output compared to the plan and publishing any deviation to initiate corrective action.

3) Plan and Control Priority - involves translating the master schedule into individual components to be produced, determining how many and when required.

Figure (1) shows the activities required for planning and control and indicates clearly the relationship between the master production schedule and resource requirements.



MASTER PRODUCTION SCHEDULE DEVELOPMENT AND IMPLEMENTATION

FIG. 1

An interesting result from an improved understanding of the control system is the significant change in the role of the sales forecast [52]. Companies need no longer spend much effort trying to improve the accuracy of a short range detailed product forecast. Flexible priority planning and control systems which can react quickly to change, will overcome errors in such forecasts. However, the vital need for sound capacity planning increases the pressure to obtain better long range forecasts, particularly anticipating upturns and downturns in business cycles.

3.4 Resource Requirements Planning

A master production schedule must be considered in relation to the load it places on the resources of the company. If the resources are not adequate to meet the schedule, the resources must be increased or the schedule modified to suit available resources. Unless a thorough planning of resource requirements is carried out before the planning of production, on-time deliveries cannot be guaranteed, and much of the effort spent in detailed planning is wasted. Such an exercise is called 'resource requirements planning'.

The resources considered can vary from design personnel to plant square footage. Should, for example, the resource under consideration be production capacity, this may be sub-divided if required into either the entire machine shop or the functions carried out within the machine shop, e.g. heavy casting, machining or fabrication.

A still further breakdown would identify work centres or even individual machines; however, at the resource requirements planning stage, such a breakdown would not be necessary. The intention is not to determine the exact load on an individual resource, but rather to evaluate the overall impact of a given master production schedule. Resource requirements planning is conducted on a 'macro level', using general approximations of load, and a precise 'fit' is not sought. The important thing is to be able tc present the alternative loads quickly, so that several different master production schedules may be tried out. The greater precision of loading individual equipment, etc., is carried out later at the 'capacity requirement planning' stage.

The process of developing a master production schedule is essentially one of trial and error. A useful construct to employ is the load profile; this presents the approximate needs in terms of the various resources by time period associated with one unit of a particular product being put in the master schedule in a base period. Such load profiles are developed for each product, but need only be done once in a lifetime for a product. However, should the product be redesigned drastically, a new load profile will be required.

Extending load profiles by the quantities called for by a given master production schedule and summarising them, period by period, is a simple matter using a computer. The result is a report printed or conveyed through a visual display unit, showing the effect of the master production schedule over the entire planning horizon, on the various resources for which profiles are maintained. These are called 'resource requirements profiles' and provide a good indication of the loads that can be expected for a particular schedule. The loads may be segregated into individual product lots, to show which of these are causing potential capacity problems. See Figure 2 [49]

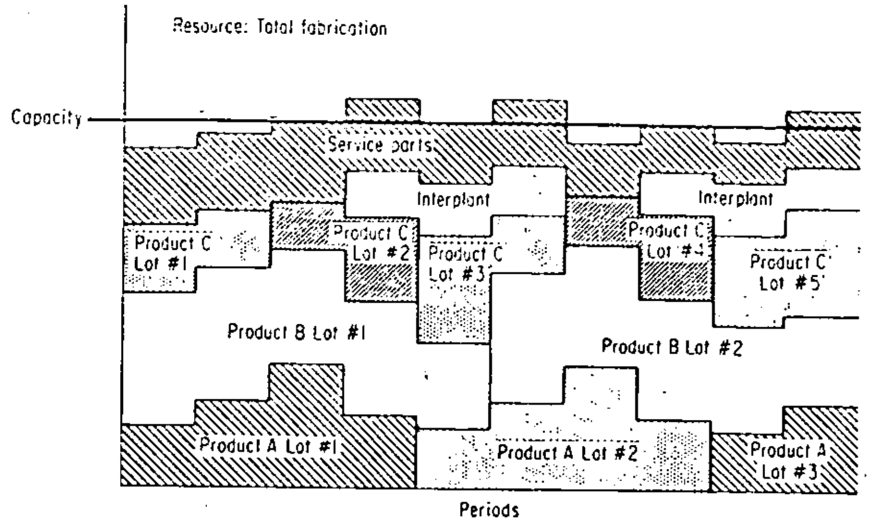


FIGURE 2 A resource requirement profile.

If the load generated by a proposed master production schedule is unsatisfactory because of significant overload management must decide whether to increase the resource in question to meet the load, or modify the schedule to reduce the load. Should an underload be shown it will indicate the need to reduce the resource or, more likely, to add more work onto the schedule

Everdell [24] considers the master schedule to be the key element in the overall control system; it is the means of co-ordinating the management functions related to the flow of materials, from suppliers through production to customers. The master schedule is the brain centre of production control. It enables all the related functions in manufacturing to complement each other by being a contract between the different functions. It should be regarded as the basis for resolving the inevitable conflicts between the management functions. The master schedule converts customer demand into production requirements by time period. It thus becomes a manufacturing plan for the use of facilities, equipment, manpower and materials; so it becomes the basis for management control of component inventories, production and purchasing. In addition it becomes manufacturing commitment to marketing, and marketing commitment to customers, resulting in the control over finished goods inventories and their distribution.

Everdell states that by using the master schedule as the basic control system, it permits an almost universal adoption. It can be readily modified to suit a broad spectrum of manufacturing companies. For example, it can be applied to companies that are mainly involved in assembly work, or parts fabrication, or both. And these companies can feature continuous or intermittent production of standard or special products. They can deliver from stock or make products to order.

For any 'live' system to be successful it is not only important to produce an effective plan, it is of paramount importance that the system is under control. To allow the system to be controlled it is necessary to have feedback and data flow between all functions within the system. It is the flow of control data that links all these functions and makes them work together as a unified system.

An example of lack of co-ordination within a manufacturing concern was outlined by Oddey[48]. The company concerned was persistently failing to meet its delivery commitments, yet carried a huge inventory of work in progress. Investigation revealed a fundamental lack of understanding among production management of the inherent problems posed by the company's manufacturing and assembly activities, which led to a serious failure to co-ordinate the activities of the feeder departments with the requirements of the assembly and erection shops. The feeder departments organised work to suit their own domestic situation, which resulted in the assembly and erection shops receiving a plentiful supply of parts not immediately needed, but were constantly short of items required to complete the jobs they were currently working on. This was a 'classic' production control problem, where supervision spent most of their time chasing shortages.

The solution was comparatively simple to formulate but not so simple to implement because it meant changing long established practices. For example, staff in the machine shops believed that batching parts to reduce unit set-up costs must always be the best course of action, even though, in most cases, some of the items in each batch were not needed for months ahead.

To focus the attention of all the parties concerned with manufacturing the product, and thereby effectively co-ordinating their individual activities, stage/week charts were introduced. The purpose of the stage/week chart was simply to show the broad sequences in which parts and assemblies of parts were needed to suit erection purposes. A stage/week chart was issued to every production shop; this enabled shop management to decide which job in the queue waiting against each machine was the correct one to load next.

The introduction of stage/week charts proved successful in three companies, according to Oddey, with an improvement in the flow of parts through production to final assembly. This in turn reduced shortages and the consequential disruptive effect of expediting the completion of missing parts.

Perhaps the most interesting lesson of all emerged in the two companies who had hitherto been using computers to 'assist' their production control. The stage/week chart routine was entirely manual and is very basic and easy to understand. The shop supervisors and others involved had a full understanding of the new routine; they began to come forward with ideas and suggestions of how things might be improved for everyone if these routines were put on the computer.

Only minor changes were needed in the existing computer programmes. Once these were carried out and the results published, the print-outs were used far more intelligently than their predecessors had ever been.

3.5 Priority Dispatching

Wight [73] argues that production supervisors should not be placed in the situation where they have to decide the priorities of the backlog of work in their department. The backlog is caused by production control's usual abdication of responsibility for keeping work flowing to the supervisor at a steady rate. Production control should hold back orders when the production capacity is fully loaded. This will enable production control, not production supervisors, to identify the job priorities immediately prior to release. The avoidance of large in-plant queues will also reduce the expediting activity associated with queues. How many expeditors would really be necessary in a company where there was only one job behind each operation ?

Wight's concept may be applied effectively in a flow production environment where all the batches of work flow through the processes in the same sequence. However, in a jobbing production environment, the situation is quite different and the application of the above concept would present difficulties. It is usual in jobbing production for the sequence of operations to change from product to product, and work waiting for a particular operation to be carried out, will comprise many different items which have arrived from many different previous operations in a random manner. The sequence in which this work should be processed bears no relationship to the sequence of work hitherto. The start of every operation should be the result of a decision that it is the right job to be processed next, taking account of the ever-varying mix of work and the possible alternative routings.

A technique which may be used to identify and maintain priorities among jobs in the factory is called 'Critical Ratio Scheduling'. The critical ratio itself is an index by which the relative priorities of jobs can be determined. It is a time relationship between when a product is required and when it can be supplied. The computation of the critical ratio is as follows :

$$\text{Critical Ratio} = \frac{\text{Date required - Today's date}}{\text{Days required to complete the lot}}$$

The importance of the critical ratio value can be summaraised :

Greater than one means there is ample time to finish the job ahead of schedule.

Exactly one means that the job is on schedule.

Less than one means that the job is critical and will have to be expedited if it is to be completed on schedule.

The farther behind a job is, the lower the critical ratio and the more critical the job is.

The following advantages are claimed with the application of critical ratio scheduling -

1) The relative priorities among jobs are established on a common basis.
2) The status of each particular job can be determined.
3) The schedule can be adjusted automatically when there are changes in demand or job progress.
4) Both stock and make-to-order jobs can be compared on a common basis.
5) A properly installed critical ratio system, with the necessary feedback, will help eliminate expeditors and the scheduling crisis of production.
6) Critical scheduling is a dynamic system.

Wassweiler [69] considers that other options are available through material requirements planning that can be applied to critical ratio shop floor control. Some of these techniques are : audits to ensure the calculated lead time of work remaining is consistent with the offset lead time used in the inventory master record, or utilising pegging methods that discriminate between work-in-process for customers' orders and orders being run against an inventory forecast. Knowing which jobs are for customers and which are for inventory can aid shop planning and maintain proper emphasis.

Early simulation studies designed to screen a large number of possible priority dispatching rules were carried out by Rowe in 1958 [58] and Baker and Dzielinski in 1960 [2]. Both studies showed the superiority of the 'shortest operation time' rule. These preliminary findings prompted further work to be carried out in the area of priority despatch decision rules. The Nanot Study [44] tested ten static and dynamic rules. In static rules relative priorities stay the same once assigned. With a dynamic priority rule, however, the relative priority position changes through time as, for example, with a due date priority where a new order entering the queue might go to the head of the line.

An alternative basis to static versus dynamic rules is to classify the priority dispatching rule on the basis of the information available. A local rule determines priorities entirely on the basis of the information available about the order in question at the time it was initiated; for example, its processing time or due date. More global rules might take into account overall job load, the status of the work centres downstream, or changes in due dates.

The Nanot Study showed that the 'shortest operation time' consistently had the lowest mean flow time and concluded that the shortest operation time rule is an excellent local rule from most points of view. The rule is realtively insensitive to errors in estimating process times. It would seem that a priority dispatching decision rule superior to the shortest operation time would probably have to be one with a broader horizon which might 'look ahead' to anticipate bottlenecks which could produce long waiting times.

Conway [18] also concluded that the shortest processing time priority rule was probably best over-all, but considers it appropriate to distinguish 'who' is setting the due dates for orders released to the shop floor. If the due dates are set by an external agency, and without any regard to processing characteristics of the job itself, its contemporaries in the shop, or the priority rule to be used; then the problem is simply to find a procedure that is capable of 'enforcing' such a set of due dates.

When the due dates are in some sense 'internal' and can presumably be rational, one must jointly select a priority rule and a due date assignment procedure. Due date assignment in this case is closely related to the problem of predicting individual shop times. Since the shop time depends not only on characteristics of the individual job and the particular priority rule in use, but also on the nature and status of the other jobs in the shop at the same time, perfect prediction is, for all practical purposes, not attainable.

The problem is one of finding a combination of due date assignment procedure and priority sequencing procedure such that :

(1) The 'natural' shop time of a particular job can be predicted with some precision.

(2) A due date can be set based on both the natural passage of time and exogenous considerations of relative urgency.

(3) The priority procedure can react to this due date to accelerate or retard a job with respect to its natural rate of progress.

Conway suggests that a great deal more work needs to be carried out in this area and that computer simulation techniques can be an effective tool for the task.

Berry and Rao [6] in their experiments with the critical ratio rule found that static critical ratio rules significantly out-performed dynamic ones and suggested that this finding will help in reducing the overly nervous M.R.P. systems, such as those that tend to be associated with net change information systems, producing dysfunctional results at the shop floor level.

3.6 Manual v Computer Scheduling

Burbidge questions the value of using computers for operation scheduling[13]. It is submitted that an intelligent human being can perform the task of scheduling better than the computer and more economically. It is also submitted that even in the future should it prove possible to programme the computer for efficient operation scheduling, it would still be undesirable because this type of work is highly valued by foremen and workers on the shop floor, and because this form of participation in decision making is essential for workers' motivation and job satisfaction.

Western Electric have developed an interactive scheduling system [30]. The system can use either typewriter or display terminals and thereby places the production superviser, or scheduler, in a loop with a computer programme. By interacting with the programme the scheduler develops and/or alters the schedule. Schedules are generated by making choices from among sets of decision rules, for example, rules for the acceptance or rejection of orders, rules for sequencing orders, and rules for allocating the use of overtime.

The computer programme can carry out simulation of shop schedules so that the supervisor can test various alternative assignments and try to anticipate future problems. Various reports, such as shop status, a history of work by operator or by machine, or load summarised by standard hours, can be called for at any time. The interactive nature of the system provides operating personnel the opportunity to test a wide variety of solutions. Involvement of this kind should promote motivation of the people concerned and improve job satisfaction. Manual intervention can also improve the effectiveness of the system by overcoming the restrictions imposed on a computer programme by the large number of variables in a manufacturing system. Lockyer [13] has identified over one hundred scheduling rules alone, and although each one of these has some value in particular circumstances, it is obvious that none of them are universal in their application.

CHAPTER IV

LEAD TIME

4.1 Control of Lead Time

The success or failure of production planning and control is governed by the information used in making decisions which enable the manufacturing concern to operate effectively. The lead times used in planning and control systems can be regarded as one of the more important factors in the decision process. However, lead times are particularly difficult to quantify, mainly because in practice they are in a continuous state of flux.

Lead times can be divided into two separate categories :

(i) vendor lead times
and (ii) manufacturing lead times

Although the elements which constitute the lead time are identical in each category, the degree of control which a manufacturing concern has on each is normally different.

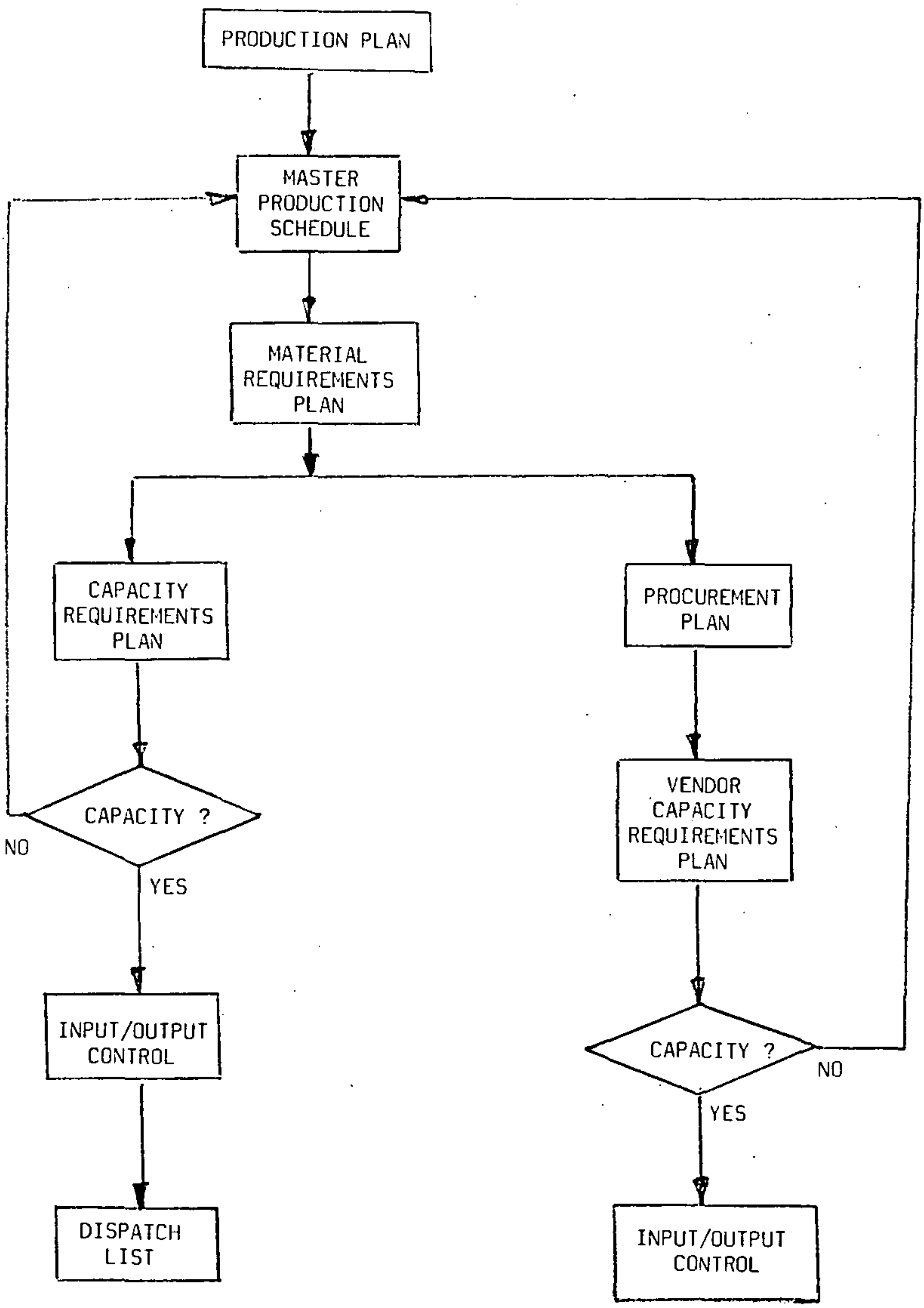
Vendor lead times can be difficult to influence since the load/capacity relationship of a supplier is not usually within their customer's control and supplier performance will vary. It is known for large customer organisations to have control of their supplier's production resources, particularly when the supplier does not have the knowledge or facilities to apply sophisticated control techniques to its manufacturing processes.

Methods for minimising the effects of uncertainty of a supplier, particularly if these are caused by the uncertainty of customer demand, can include the reservation of supplier capacity, the detailed orders in time and quantity being placed with an agreed lead time. Another technique will be to negotiate terms with the vendor which encourage him to hold stocks for the customer.

If a supplier invariably delivers late it is fatal to extend the delivery lead time; it is much safer to regard poor vendor performance as a vagary of supply and either replace the vendor or adjust the Safety Stock levels.

One of the primary missions of production and inventory control is the construction of a master production schedule. This schedule recognises capacity limitation and focuses on planning and controlling the productive capacity of the "inside firm". Fisk [27] states that it is also necessary to consider the planning and control procedures for the "outside firm", i.e. the vendor . Without the vendors' co-operative efforts, valid master production schedules are not possible. This co-operation is particularly important because in the typical company, purchased material content exceeds labour content by a substantial amount.

To assist the inside firm in enlisting the co-operation of vendors and knowing what the vendors are doing in terms of meeting their schedules, it is necessary for the inside firm to incorporate procurement planning and control in the production planning hierarchy (See Figure 3). A master procurement plan will include a forecast of those items which must be purchased in future periods. In constructing the procurement plan a company may start with a material requirements plan and from this generate the planned procurements to meet production requirements, while making necessary adjustments to inventory or backlog of purchased items.



PRODUCTION/PROCUREMENT PLANNING HIERARCHY

FIG. 3

Once the procurement plan is completed for a given time period, it is sent to purchasing for disposition. It is then purchasing's responsibility to procure the materials at the right price and quality and on time to meet the firm's production schedules.

The above system should improve vendor delivery performance by increasing the amount of communication and co-operation between vendors and the firm. If estimated throughput times are made available for each vendor on an item-by-item basis, the system provides an excellent control device against which vendors can be measured. This procedure relieves purchasing of much of the day-to-day effort involved in handling paperwork and expediting needed materials, and thus frees them to do the important jobs of negotiating and vendor selection. The procedure also creates vendor delivery schedules which are realistic and which correspond to the master production schedule of the firm. Internal manufacturing lead times can be directly controlled by production management. To identify how and where control may take place it is necessary to breakdown the lead time into its constituent elements, as recognised by Wight [74].

Lead time = Set-up time + Running time + Move time
+ Wait time + Queue time

where Set-up time is the time the job is being positioned on the machine with the correct tooling available

Running time is the time the job is on the machine being worked on

Move time is the actual time the job is in transit

Wait time has been separated from the Queue time so that it can be arbitrarily associated with Move time, since in many factories the dispatching job is not highly organised and the forklift truck does not get to a job as soon as it is ready to move. In some plants an operator of a forklift truck may 'empty' one department once a day. This could mean an average wait time of half a day.

Queue time is that time a job spends waiting to be worked on because another job is already been operated on at that particular machine centre.

The set-up and running times are normally easy to establish and remain reasonably constant, being fixed mainly by technology. However, the remaining times may fluctuate considerably; they are partially intended to act as a protection against work stoppages, but mostly they develop in an uncontrolled manner as a consequence of machine breakdowns, operator behaviour and fluctuations in the arrival rates and service rates of individual items. The lack of formal control of non-productive times is one reason for high levels of work in process. It is a frequent experience that the set-up time and running time is a small fraction of the lead time, sometimes less than 10%. The queue time usually constitutes the majority of the lead time and highlights the fact that the bulk of the work in process inventory is typically not being worked on and control of work in process is poor.

Consequently, it would appear that if advantages are to be obtained by reducing lead times, it would be more appropriate to concentrate on the queue time which should prove the cheapest and most effective way of lead time reduction rather than attempting to reduce the set-up time and running time. These latter two elements of lead time should be at a minimum anyway if Method Study and Work Measurement have been involved in the manufacturing process.

This view on lead time control is endorsed by Orlicky [49]. In his exposition on lead time he distinguishes between the planned and the actual manufacturing lead time, and considers the overall lead time can be reduced by compressing the queue time. When MRP is used, the planned lead time is the value supplied to the system and is used for planning order releases. The original due date of an order reflects the planned lead time. Actual lead time reflects a revised due date which coincides with the date of actual need, if the latter has changed, since the time of order release. The difference between the two lead times, planned and actual, can be major, reflecting the order priority. The concept of 'good' or 'accurate' planned lead time must be discarded; planned lead times need not, and should not, necessarily equal actual lead times. Actual lead time is flexible, lead time is very much a function of priority, when necessary lead time can often be shortened to respond to specific needs [51].

Belt [4] in an article called "The New ABC of Lead Time Management" states that the modern concept of lead time is that it is a 'controllable' resource' like the number of drill presses or the amount of raw material investment, and should be managed like other resources to make a maximum return on investment. Companies which manage lead time like a controllable resource rather than an uncontrollable 'given' achieved better operating results, both on the balance sheet and on the shop floor, than those which do not.

This new concept immediately implies three different actions on the part of production control practitioners :

1) If lead time is a resource it must be allocated as carefully as other production resources.

2) Lead time cannot be allocated indiscriminately, just as turret lathes cannot be bought and placed in the shop without any regard for floor space and trained operators. Rather, it must be balance with other production and business resources.

3) Once allocated and balanced, lead time must be measured quantitatively at regular intervals to ensure that it is not deviating too far from plan and that it is furnishing the desired return on investment.

Valentine [68] considers selection, investigation and control techniques should be applied to lead times, but lead times have special characteristics. If the master production schedule is overstated, causing a general overload in the factory, products and components will be made within their specified lead times only by accident, or as a result of special attention, or one section independent of the others happens to be lightly loaded. Moreover, the situation will rapidly worsen as the time period of overload increases. The forecast will become less accurate as time goes by, and the validity of the due dates of orders will deteriorate accordingly.

A cost accountant, speaking on the relationship of cost to production control, made the following statement [3] "If you want to do the best possible job for your customers and for your company, control lead times."

The manufacturing lead time comes under the direct influence of the production control department. It is here that production control can do more to meet its own objectives: maximum customer service, maintaining an efficient plant operation and minimising investment in inventories. There is no one area that will do more for meeting the objectives of production control than will the control of lead times; the success of any of the techniques such as requirements planning, re-order points, critical ratio and lot sizing in the absence of good lead time control, is debatable.

Lead time control begins with the master schedule. There are three rules to good scheduling which have the greatest effect on lead times:

Rule 1 - Do not schedule more than the plant can realistically handle.

Rule 2 - Do not release any more work to the shop floor than is absolutely necessary for planning purposes.

Rule 3 - Do not allow any more time than is actually necessary to get the job done; control lead times.

If the lead times in a company's system are valid, the cumulative lead time of parts and assemblies on the critical path of production manufacture can be used to determine whether to accept schedule changes. Moreover, the manufacturing manager can evaluate more precisely the effects of any schedule changes that violate the cumulative lead time; he may then order the product to be built in less than the cumulative lead time. Obviously, if the lead times are inflated, schedule increases can be readily accommodated up to the point when the excess lead times are used up.

To allow the manufacturing system to operate effectively, with reduced lead times, management should consider carrying an extra inventory of items on the critical path to permit a fast response to schedule increases. A modest investment in this extra inventory will undoubtedly permit a reduction in lead times but with many investments, however, sooner or later it will reach a point of diminishing return. If there are many items on the critical path, management will find this approach less practical. Carrying extra stock also increases vulnerability to high inventory investment if the product schedule decreases or designs change. The balance between shorter lead times and carrying extra stock is crucial if the advantages of responsiveness to market changes are to be achieved.

In reality, increasing demand should only pressurise lead times when plant capacity is overloaded. When a manufacturer or vendor faces such a capacity problem, he is tempted to increase lead times, resulting in a larger work in process inventory which is counter productive. The answer is to solve the capacity problem, not lengthen lead times.

Should the decision be made to increase lead times due to capacity restriction, the overload will progressively increase, which can have disastrous effects on the plant. For example, suppose a manufacturer increased his lead time from six weeks to eight weeks, this would immediately generate an extra two weeks worth of work for the manufacturer which would increase the backlog, thus increasing the lead times. If the actual lead times are now observed, they will be longer than ever and if they are built into the inventory plans, orders will be generated sooner, again increasing backlogs and once more increasing the lead time. This is one of the most dangerous and most common misconceptions in industry, yet many companies have even developed sophisticated computer programmes to average historical lead times and build these into the planning system. Unfortunately, a computer is amoral; it can be used to do the wrong thing faster than it was ever possible to do it manually.

Many vendors quote longer lead times in the belief that this will give them a better chance of producing a customer's requirements on time. This again has the effect of encouraging the customer to place a larger order to compensate for demand during the extra lead time. If he once more quotes a longer lead time, most of his customers will send him more purchase orders. Eventually they will not accept inflated lead times and decide to purchase goods from another vendor. This will reduce the backlog and consequently reduce the lead time; the remaining customers' needs will be reduced in line with the lead time, again resulting in a reduced backlog. The foregoing puts emphasis on the disastrous effects on the organisation when lead times are not under control; it is important that management are fully aware of these effects.

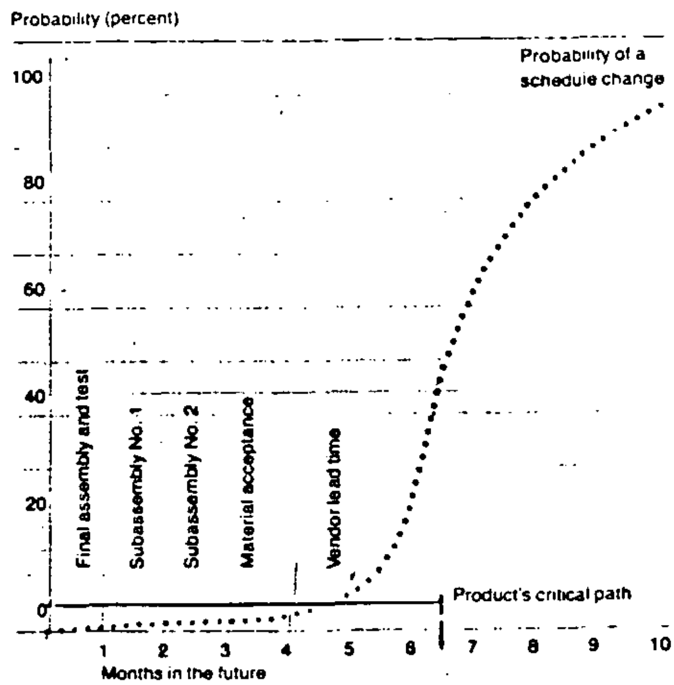
It is essential to establish objectives for lead time reduction for the directors of purchasing and manufacturing, and to hold these individuals accountable for their attainment. The initial setting of such objectives can prove difficult. At first, set the objective arbitrarily to reduce a certain percentage of lead time; this will set a target for everyone to aim for. The efforts required to achieve this set objective will demonstrate the validity of the objective and indicate if there is a need for change. This procedure may be repeated resulting in an objective reflecting a realistic challenge to management.

To a large degree, marketing and manufacturing objectives are opposed. Marketing requires a fast response to changing customer demand resulting in quick production schedule changes and greater expense in overheads and in premiums to vendors to accelerate deliveries. Manufacturing, however, would prefer a gradual schedule change in order to minimise product cost and inventory and overhead expenses, and to maximise output; but this posture reduces responsiveness. The answer is to trade off these conflicting objectives in a way that optimises results in a company.

Unfortunately, such a trade-off is difficult to accommodate. Maintaining objectivity in a trade-off analysis of schedule changes is also difficult because of the psychological pressures. When demand is strong few companies like to turn down or delay new business even though the probability of attaining schedule increases may be low, the urge to schedule them anyway is usually overwhelming.

When management succumbs to this urge, inventory and product cost objectives are bound to suffer. The answer to the problem is to maintain the shortest possible lead times for assemblies and component parts in order to allow maximum responsiveness to product schedule increases and decreases without harming inventory and product cost objectives.

A schedule to manufacture products is normally set from a sales forecast, as with all forecasts the longer the period included in the forecast the greater the probability of forecast error. An extended cumulative lead time, or even long single item lead times, will prove vulnerable to demand changes and increase the probability of schedule changes. Figure 4 shows the probability of schedule changes in relation to lead time [38].



PROBABILITY OF A FUTURE SCHEDULE CHANGE

FIG. 4

Shown on the Figure is the critical path of a typical product, totalling 6½ months. If the cumulative lead time can be reduced to 5½ months, the probability of a schedule change that violates the cumulative lead time is reduced from 40% to 5%, again emphasising the advantages of lead time reduction.

4.2 Input/Output Control

It has been previously established that one element in the lead time cycle, which can be excessively large, is the backlog of production scheduling. The erratic nature of work coming in each week cannot be predicted; companies, however, seldom measure the incoming work rate or know how erratic it is.

Figure 5 simplifies a manufacturing unit, if the flow of work through the unit is to be constant, work input 'A' must equal work output 'B'

Manufacturing Unit

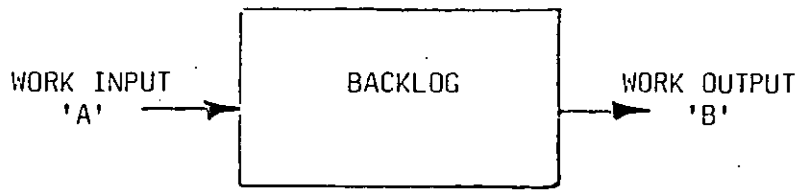


FIG. 5

If input 'A' is increased, the manufacturing unit will utilise additional capacity if output 'B' is to increase at the same rate. It is reasonable to assume the input and output rate will seldom be equal, consequently there will be a need for a backlog to minimise the detrimental effect of fluctuating demand on the unit. However, should the cverall input rate increase at a greater pace than the output rate, the backlog will be increased. Input/Output control is the major factor in controlling the level of backlog and lead times. When the manufacturing unit's output consistently falls short of input, it is necessary to either expand the capacity or reduce the input in order to reduce the capacity constraint.

The benefits of successful input/output control are cumulative. The reduction of backlog and lead time facilitates priority control, with resulting less work in process, making it easier to manage the remainder. Lead time instability is a direct result of shortcomings in planning and control. The key to stabilising and reducing lead times is control and reduction of backlog.

Input/output control addresses two problems separately - Capacity and Priority. These are approached in three stages :

First, a family of items which require a common production area are identified and capacity requirements projected for the total group. Capacity is thereby reserved and manpower and equipment requirements are planned accordingly.

Second, reduce the lead time by eliminating most of the queue time from the total lead time, leaving only order preparation time, manufacturing time and transit time. The backlog is reduced in this manner until it includes only those orders in process in the plant.

Third, select the input to match capacity for the family of items previously identified, using the highest priority selection procedure.

By applying the three foregoing steps, capacity has been reserved and committed but the selection of the specific item to be manufactured, priority determination, is not made until the last possible moment.

Input/output control must equal capacity or backlog will increase. If backlog is allowed to increase, the spiralling lead time problems such as expediting and missed deliveries, will emerge. The input should not be less than capacity or work shortage will occur and the plant and vendor will retreat to their old habits of building a backlog for security. Input/output control is working most effectively when capacity is correctly established and inventory control is pulling work ahead to avoid future peak loads. At this point management is in the enviable position of acting to stay out of trouble instead of reacting to get out of trouble.

The following results were reported after Fisher Controls initiated a system utilising the principles of Input/Output control with a cast iron foundry [29]. The programme was started during a time when the foundry's lead time was increasing from 12 to 24 weeks. The control successfully held the lead time to an average of 10 weeks initially, and this was later reduced to 4 weeks. Expediting was reduced from daily phone calls from Fisher Controls Buyers to bi-monthly phone calls by the foundry. The programme was expanded to cover 75% of Fisher Controls foundry purchases with equally good results. Vendors were initially reluctant to accept an Input/Output control programme. The idea of shorter lead time and less backlog is discomforting. However, after a short experience with Input/Output control, the vendor becomes one of the system's greatest supporters. No longer does he rely on a short range forecast from his marketing department; he has a firm capacity commitment with zero deviation for three months into the future. He has a forecast beyond three months from the source of future business - the customer's inventory systems.

The vendor is no longer vulnerable to unexpected surges of increasing orders which he has not the capacity to satisfy within the standard lead time. He is not plagued with mounting files of open orders and the inevitable multiple re-schedules which follow. Fisher Controls report that their vendors, who are involved with Input/Output control, have requested their other customers to adopt the system and offer shorter lead times to entice them.

The purchasing viewpoint of Input/Output control is that the buyer is relieved of the endless job of expediting hundreds of individual orders, and gets the opportunity to buy - negotiate better prices, better quality and develop new sources.

Inventory Control is also enthusiastic with this type of control; when the inevitable forecast error is encountered, the Inventory Planner has a faster recovery time to restore inventory levels and meet customer requirements. He does not have to resort to the 'Hot List' emergency systems. When the Sales Department calls and has an emergency order or wants short delivery for a special order, he can immediately determine what other purchase orders, if any, will be put in jeopardy and confidently make delivery promises because he now controls the priority of orders.

4.3 Backlog and Job Security

Pressures for faster deliveries and for reduced product lead times have been increased by industry's insistence on maintaining low finished goods inventories; but manufacturing people find it almost impossible to reduce cycle time because of backlogs within the plant. Gomersall [31] calls this condition 'the backlog syndrome'. To reduce backlog in a company it is necessary to distinguish between 'good' and 'bad' inventory. Once this division has been made it is then necessary to reduce, or when possible, eliminate, 'bad' inventories.

Good work in process inventories may include the following :

1) Inventory required by a production process (such as, bake for three hours after painting)
2) Temporary banks for balance. Such inventory occurs during the workday but, by definition, must be eliminated during the day in which it has been created.
3) Banks for breakdown or maintenance. In highly sophisticated plants, downtime for maintenance and breakdown may be carefully computed. Inventories are then created and stored to compensate for lost machine time.

'Bad' work in process inventory is any inventory other than the above, for example :

1) Inventory queued for processing in excess of station time.
2) Banks created by loss of balance
3) Banks created by over-scheduling
4) Banks for rate guarantee
5) Banks for schedule guarantee. It is an old manufacturing practice for the supervisor to maintain a bank of goods to assure compliance with the week's schedule. By doing this, line balance, random absenteeism, and performance variation disappear as critical elements requiring managerial attention.
6) Banks for capital equipment utilisation. It is considered good business practice to use expensive pieces of capital equipment to the fullest extent possible. This encourages the use of such equipment irrespective of the need of the good being produced on it.

Once 'bad' work-in-process has been built it will tend to remain at one level. The prime motivator for the maintenance of backlogs is the sense of security it gives to both operators and the supervisor.

If the production team gets a sense of security from the knowledge that there is plenty of work to be done, this hypothesis can be made : as the amount of work to be done diminishes, the sense of security diminishes. The only effective way an employee can resist the reduction of the work in process is to try and maintain it. The methods employed to maintain the backlog at an acceptable employee level can be subtle. Other than actually reducing the work pace, one or more of the following techniques may be employed :

1) Increase of lost time or down time by questioning set-ups, tools work fixtures, etc.
2) Random depletion of parts and supply items.

3) Increase in indirect time through visits to personnel, visits to Stores, increased number of grievances, etc.
4) Increase of re-work for quality reasons.

Once the security level of in-process inventories is reached, the employees and supervisors pay little or no further attention to 'building security'. Noticeable traits of the operator above the security level are the converse of those outlined previously. These conclusions were reached by Gomersall after carrying out extensive controlled experiments to confirm his backlog syndrome theory. He also considers that 'feather bedding, automation and job guarantee' all have their roots firmly embedded in job security. Most major job security controversies occur in industries where it is difficult for employees to 'store work'. It is logical to assume that all employees will tend to develop an informal assurance of security if this is not guaranteed by their company or union.

There is a word of caution for those embarking on computerisation and total management control systems. Many of the efficiencies which such systems bring, result from the reduction or elimination of excess inventories and decreased process times. Unless careful consideration is given to the psychological effects on the people who depend on their 'pads' for security, irreparable damage may be done to the organisation.

There is a need to involve the workforce in any backlog reduction plan and secure their acceptance of the advantages accrued by the reduction. It is necessary to belay their natural fears of job security; this will be no mean task and reassurance needs to be frequently given that lead time reduction will promote a more competitive stance of the company, attracting additional orders due to better customer service, the net result being long term job security for the employees.

Wight [73] considers that the problem of the security level of work built by operators is aggravated by management's fundamental rule of measuring people on the functions they control. The supervisor is measured on idle time; if a man is not working, pressure is applied to the supervisor to find him work or get rid of him. On the other hand production control personnel feel they are responsible for delivering goods to schedule. It would be more logical to place the responsibility for delivery with the supervisor and let production control be responsible for keeping the work flow through the shop at a steady rate. Some companies charge all idle time for the lack of work to production control.

CHAPTER V

MATERIAL REQUIREMENTS PLANNING

5.1 Handling of Information

Production and inventory control is achieved primarily by receiving, processing and passing on information. The handling of information is one of the major determinates of the effectiveness and efficiency of a manufacturing concern.

The size of the concern, the complexity of the end products and the manufacturing process effect the amount of information which needs to be handled. Buffa and Miller [11] classify production units into two categories: continuous systems, and intermittent systems. This dichotomy is largely a function of process technology, since continuous systems are those designed to produce a continuous stream of products, while intermittent systems are geared to producing in batches or lots.

The difference in planning, scheduling and control between the continuous system and intermittent system is substantial. While both may be producing finished products for inventory, the intermittent nature of production of parts, components, and products of the latter produces a more complex detailed scheduling problem. The nature of forecasting and planning production lot sizes is unique because of the dependent nature of the demand for parts and components. Demand for parts and components is dependent on the production schedule for the primary product which, in turn, is dependent on market demand. In the case of complex assembled products, these may have sub-assemblies that in themselves may be produced for inventory to be sold as spares.

Prior to the application of the computer in industry, the greater the amount of information to be processed resulted in increasing the constraints on the controllers. Manual systems never really worked because of their limitations in the speed of response and the cost of control which of necessity made them functionally incomplete. The failings of the formal recording, planning and control systems were compensated for by the introduction of an informal system seeking to respond to immediate needs.

The formal system can be identified as a 'push system' which controls the inventories and scheduling to meet the customers needs. The informal system is related to the 'pull system' where progress chasers, expediters or priority lists pull the most urgent or overdue orders through the works. The informal system is usually regarded as 'firefighting' identifiable by the following actions :

(i) preparing 'hot-lists' of products to be expedited

(ii) kitting materials from stock ahead of schedule to find out if there are any shortages

(iii) batch splitting to avoid manufacturing idle time caused by poor planning of the formal works order launching system

(iv) cannibalism of kits or work in process

(v) urgent requests to vendors to supply material ahead of normal lead time, usually involving excessive costs.

The first computer applications around 1960, in production and inventory management represented the beginning of a break with tradition. The problem of information storage, processing and retrieval, was reduced and many of the older methods and techniques devised in light of these constraints suddenly became obsolete. The companies which maintained the old methods for use with the computer found little advantage; they merely accelerated the use of inappropriate techniques.

It became feasible and desirable to sort out, revise, or discard previously used techniques and to introduce new ones which previously would have been impractical or impossible to implement. It is now a matter of record that among manufacturing companies that pioneered inventory management computer applications in the 1960's, the most significant results were achieved by those who chose to undertake a fundamental overhaul of their systems, not those who refined and speeded-up existing procedures [49]. The result was the abandonment of unsatisfactory techniques and the substitution of new, radically different approaches that the availability of the computer made possible.

With the declining cost of computation and the rising cost of inventory it became an even more worthwhile exercise to use computers for inventory control. In the area of manufacturing inventory management, the most successful innovations are embodied in what has become known as materials requirements planning systems (MRP).

Material requirements planning was developed out of frustration with the complexity of large-scale manufacturing control and with the failure of the statistical inventory control (SIC) methodology to provide adequate management control within reasonable cost constraints.

5.2 Limitations of Statistical Inventory Control

Statistical inventory control has certain weaknesses, particulary when applied to intermittent systems. There is no need to statistically forecast the requirements of a component. Once the production plan for all items in which the component is used has been established, then the requirements of the component follow, as dependent demand, by simple arithmetic.

SIC methods rely on a smooth demand pattern for components. It has been recognised elsewhere in this thesis, particularly in batch production systems, that lower level demands are usually 'lumpy'. Stock control systems which replenish stocks immediately following large demands can result in unnecessary stock carrying cost due to the inactivity of demand which follow the depletion. This cost is also aggravated by the cost of carrying safety stock associated with statistical theory.

Where several components are needed for a single assembly, the inventories for those individual components should not be treated in isolation.

Consider the case where twenty different components are required for a particular assembly. Suppose, under independent control of the components, that each component has a 95 percent chance of being in stock. Then the probability of being able to build the complete assembly is only $(0.95)^{20}$ or 0.36, that is, 64 percent of the time at least one component would be unavailable, thus delaying the completion of an assembly.

Material requirements planning overcomes the limitations of statistical inventory control basically with the provisioning of materials in the quantities required at the time required.

5.3 Application of Material Requirements Planning

Material requirements planning is not a new concept; logic dictates that the Romans probably used it in their construction projects, the Venetians in their shipbuilding, and the Chinese in building the Great Wall. Building contractors have always been forced into planning for material to be delivered when needed and not before, because of space requirements.

The amount of literature on M.R.P. appears very modest when compared with the amount available on S.I.C. This can be partially explained by the fact that M.R.P., although considered superior to S.I.C. for manufacturing inventories, was difficult to apply in the pre-computer era. Moreover, M.R.P. is based on very simple ideas and offers fewer possibilities for abstraction than S.I.C. Therefore, mainly practical people are dealing with M.R.P. which could never become of great interest to theoreticians.

In jobbing and batch environments the smooth flow of production depends upon a number of factors, a major one being the availability of required material in correct quantities in the right place at the right time so that production schedules can be met. The production schedule relies upon forecasts for future demand and actual customer orders. When a company is able to forecast future demand accurately, the problem of the availability of material diminishes, but when accurate forecasting is not possible the provisioning of material becomes an important issue, particularly when operating with the constraints of available cash which is imposed on most companies.

It was mentioned earlier that the formal 'push' system of production and inventory control relied upon the use of 'hot lists'. To be effective a series of hot lists are necessary which break down the requirements and associated shortages into time periods showing in which period a shortage would occur if the items are not expedited. This concept, if extended through enough time periods to cover the entire manufacturing lead time, is, in effect, the basis of materials requirements planning or time phased order points.

The distinction between material requirements planning and time phased order points is that time phased order point is applied to service parts and finished products. The system processing logic is identical to material requirements planning except in the manner in which item demand is arrived at. Requirements for independent demand items are forecast because they cannot be calculated.

Material requirementsplanning is a computer program for production. It enables management to time in the most efficient way, the ordering and manufacturing of components and sub-assemblies that make up completed products. In a broader sense, however, it represents a complete set of related activities that begin with forecasting and order entry, and end with feedback from the shop floor. This feedback closes the loop and thereby allows planners to schedule within expected capacity limits.

The master production schedule, considered in detail elsewhere in the thesis, is the main driving force behind the MRP system. It provides the order release dates by time phasing lead times and quantities for production derived from forecasts and actual requirements for a product. Material requirements for the product are identified by exploding the product, thereby creating a complete list of parts and sub-assemblies called the 'bill of materials'

With the product quantity given by the master production schedule, the explosion technique presents the 'gross requirements'. The 'net requirements' are calculated simply by subtracting any products, sub-assemblies or parts which are in store or already in process from the gross requirements. It is important that parts are subtracted in the order given above, i.e. products first, or the true net requirements at each level of production will not be shown.

By off-setting the lead times, the order release dates for net requirements are calculated using the product requirement date on the master production schedule as the datum.

5.4 Mixed Systems

An MRP system user may feel that not all inventory items warrant a sophisticated approach for procurement. If certain items are excluded from the MRP system and controlled by some statistical inventory control technique, a mixed system is created.

Usually a mixed system is obtained by performing an ABC value analysis and placing the low usage value items 'C' under statistical inventory control. Orlicky [49] stated that there also exist MRP systems that cover 'A' items only, but in his opinion only purchased items 'C' may be considered exception to the rule that an MRP system should cover all classes of inventory for purposes of priority planning. For purposes of assembling the product, the lowly 'C' item is as important as an 'A' item - both must be available in the right quantity at the right time. Furthermore, some 'A' items have components classified 'B' and 'C', and shortage of one of the latter will prevent the completion of the 'A' items.

A situation in which a mixed system would be necessary occurs when items with long delivery lead times present a cumulative lead time which exceeds the planning horizon of the MRP system. The MRP system would produce orders that are behind schedule at the very moment of release.

Praise for the accomplishments of the MRP system is well documented along with experiences of disappointment. Berry and Whybark [7] report that "The APICS MRP crusade has been closed and pronounced successful". Evidence of the success is shown in the growing number of MRP systems that have been installed in industry and the diverse nature of the companies making these installations. APICS members report significant operating improvements in such areas as inventory control, production scheduling, delivery performance, and operation costs [54].

Disappointment would appear to occur in most instances, not with the theory behind MRP, but in the application. It has been mentioned earlier that failure of the MRP system can be expected if it is simply grafted onto an existing system. File data integrity pertaining to inventory status data and the bill-of-materials data is a pre-condition for the system's effective operation. Orlicky [49] states that it is a fact that typically the inventory status data and bill-of-material data are chronically in poor shape under any system preceding the installation of MRP. Under a stock replenishment order point system it does not overly matter that inventory records are unreliable and that bills of material are inaccurate, incomplete or out of date. Order point acts merely as an order launching system, and it must be complemented by an expediting system in order to function at all.

Education of management and users of a proposed MRP system is absolutely necessary if the system is to have any chance of success. The implementation of MRP is a major challenge to management and requires commitment of large amounts of money and time. It must be properly planned for with the involvement of everyone who will be associated with the system. The company, as well as individuals, must believe in MRP and both must recognise the long term benefits because the project duration is longer than most people anticipate even when all the required software is available. Many production/manufacturing managers are trained to deal with day-to-day problems, and are impulsive by nature [41]. Left to such people MRP will never become really effective because, in addition to converting the system, it is necessary to ensure that the attitudes of people using the system also change. It is a serious mistake to implement an MRP system when the managers and other users still think in terms of independent demands. The users themselves must be actively involved in the project; the staff should be informed that a requirement planning approach is going to be used for running the business so that they do not maintain informal systems in parallel with the formal one. People have to be sold the MRP strategy; it is only then that they will appreciate the facilities available and allow themselves to be part of the system.

CHAPTER VI

LOT SIZES

6.1 Economic Criteria

The lot size problem will be limited to a manufacturing situation where raw materials and components are processed to the stage where a product is made available to satisfy customer demand. In such a situation the determination of lot sizes can be divided into two types of supply -

(i) The purchase of raw materials and components from an outside supplier, and

(ii) the supply of the raw materials and components for processing at different levels of manufacture within a company.

The objective of inventory management is to maintain optimal levels of inventory consistent with customer demands and plant capacity. Management must determine what to order, when to order and how much to order. This is not an easy task for there are many conflicting goals. Nevertheless, management must inevitably make the decision to order what it considers to be the 'right' quantity.

A considerable amount of literature is available to the manager which presents solutions to the lot size decision problem. The majority of methods employ solely economic criteria to determine a particular lot size, generally in the form of a balance between ordering or set-up costs and holding costs.

The decision to plan inventory lot sizes on ordering or set-up costs and holding costs has certain limitations and there are other factors which, in the practical application of the lot size, may well be more significant than the economic criteria. Other considerations may include:

(i) Physical dimension	-	due to storage difficulties, large volume components are usually ordered in small lot sizes
(ii) Product life cycle	-	if the life cycle of a component is known there would be no advantages in producing the component in lot sizes greater than the known demand
(iii) Irregular supply	-	to compensate for irregularities in supply, it is advantageous to order in large lot sizes
(iv) Supplier lot size	-	it probably will have economic advantages to order lot sizes which match the manufacturing lot size of the supplier. It is very unlikely that the order v holding cost balance will produce similar lot sizes for both customer and supplier
(v) Scrap rate	-	when the scrap rate for a process is high it will be necessary to increase the lot size to ensure the expected quantity is made available
(vi) Shortages	-	the larger the lot size the frequency of possible shortages will decrease. The probability of a stock-out increases as the replenishment order is due
(vii) Tool life	-	a lot size can be determined by the life of the tool producing the item
(viii) Process capacity	-	where a process or equipment has a limiting capacity it might be reasonable to use the capacity as the lot size or a discrete division of a lot size

(ix) Product Structure - there are advantages in setting lot sizes to suit the requirements of items, sub-assemblies, etc., at higher levels in the product structure, otherwise an imbalance of parts will result. This basically is the independent/dependent demand concept which considers that lot sizes are dependent on the demand at the next higher level in the structure. Only the highest level, the product, should be considered independently.

(x) Price - discount for bulk orders, anticipation of price rises and a 'one-off' bargain might well decide on the quantity to be purchased.

In many instances the lot size decision is influenced by the item cost and usage rate in relation to other items in the A B C classification. The rationale of A B C classification is the impracticality of giving an equally high degree of attention to the records of every item in inventory. Orlicky [49] considers the A B C concept irrelevant with the application of computers, equal treatment of all inventory items, as far as planning is concerned, is now feasible. However, Orlicky concedes that there could be exceptions such as certain extremely low cost items, especially purchased ones, that may have safety stocks and be ordered in large quantities. Such exceptions are made not because of the inability of the computer system to plan and maintain the status of such items but because of the impracticality of accurate physical control.

One of the limitations of applying an economic based formula to arrive at lot sizes for individual items is the cumulative impact the individual optimal policies have on the total cost of inventory investment. A company's resources are necessarily limited and it would be quite unreasonable to expect a company to automatically find sufficient capital to finance the total inventory associated with optimal levels of individual items. To overcome the excessive investment associated with individual item policies it is necessary to find a rational policy for the aggregate inventory.

6.2 Families of Items

The first to consider a departure from the stereotyped approach to lot sizes was W. Evert Welch [71] who recognised that very significant savings could be made by applying the theory of EOQ's to families of items, even without evaluating the cost factors in the formula, specific values of ordering costs and holding costs were not used.

Welch's approach to EOQ calculations has significant advantages, particularly when compared with intuitive methods. A constant factor is applied to all items included in the 'family' which eliminates the uneven treatment of individual items. The normal outcome is to reduce the lot size inventory of the family of items while continuing to place the same number of orders, or to reduce the number of orders while holding the lot size inventory constant. Welch pointed out that his method did not produce the most economical results, just more economical than intuitive methods.

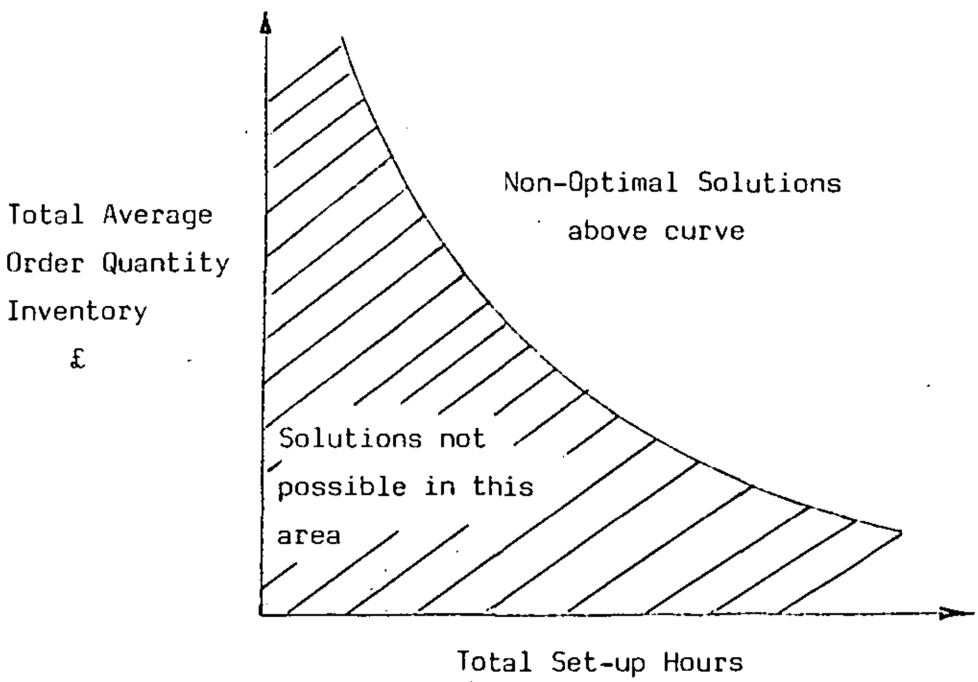
Mentioned earlier was the fact that there may well be other constraints which make it impractical to achieve the full benefits of EOQs. Among these are shortage of capital for investment in inventory, restricted space to store inventory, too few skilled set-up men and limited capacity available for manufacture.

A technique called LIMIT (Lot-size Inventory Management Interpolation Technique) was developed in 1963 as part of a special project for the American Production and Inventory Control Society. LIMIT is a technique for obtaining the most economical lot sizes when there is a limitation on the number of orders which can be processed. The limitation may be caused by the number of order-handling personnel, set-up men, or machine time available. LIMIT is designed to handle a family of items which pass over common manufacturing facilities: the technique is applied in two phases -

Phase 1 - Trial economic lot sizes are calculated for each item in the chosen family, using a standard EOQ equation. The total set-up hours required for those 'economic' lot sizes is then compared with the total set-up hours required for the present lot sizes. New LIMIT order quantities are then calculated which result in a total of set-up hours equal to the present total. The result usually is to reduce the total lot size inventory substantially without changing total set-up hours, giving benefits from reduced inventory investment without changing operating conditions.

Phase 2 - A series of alternatives is presented for the family of items, showing the effect on the lot size inventory when changing the present ordering conditions. It reveals what happens to inventory when more orders are placed or more time is spent on setting up machines. The number of alternatives can be varied to suit the existing conditions. This phase of the programme presents for study the alternatives available if it is desirable to move in controlled steps from present conditions towards operations which result in lower total costs.

Figure 6 shows the average order quantity inventory for various alternative set-up levels for a family of items. The curve is sometimes called 'The Exchange Curve'.



CURVE OF LOT SIZE INVENTORY V's SET-UP

FIG. 6

Closely related to the LIMIT technique is the application of the 'EFFICIENT SURFACE' approach to lot sizing by Feeney [26]. Inventory control operations involve two distinct types of problems which may be identified as 'tactical' decision problems and 'strategic' decision problems. The solution to the tactical problem defines a family of decision rules while a solution to the strategic problem involves a final selection of some particular member of this family. Feeney suggests that much attention has been given to the tactical decision problem; the methods typically employed to solve the strategic problem are frequently less than satisfactory.

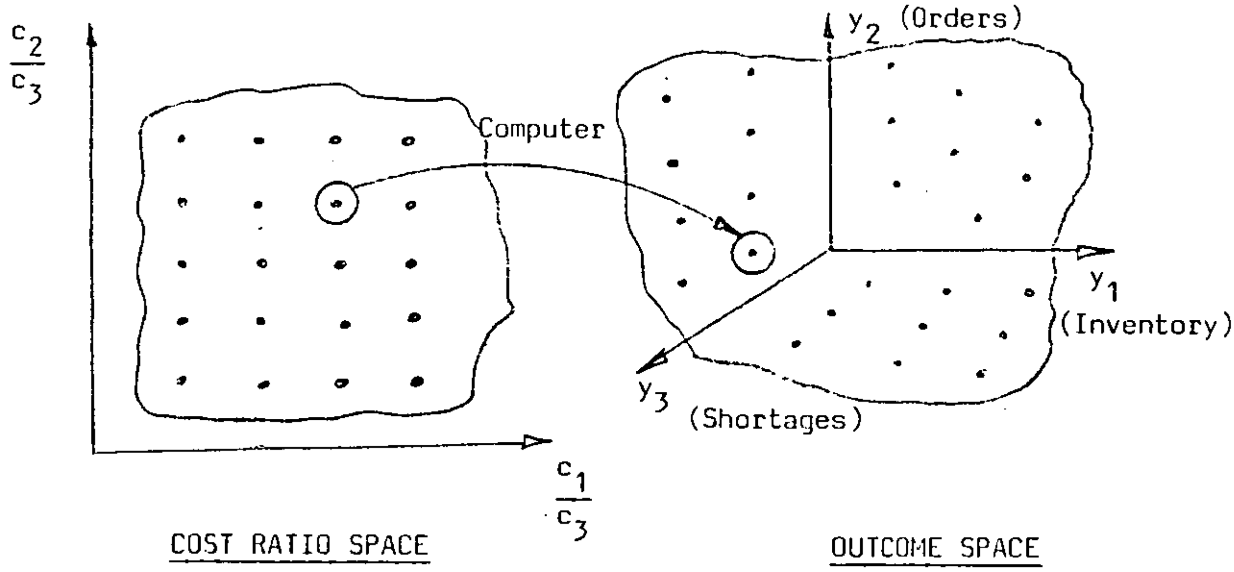
Feeney criticises the costs used in formulating the exchange curve. The cost of holding inventory, for example, involves not only the cost to the company of obtaining money but must also take into account the policy restrictions the company places on the extent of indebtedness which, in many cases, may be entirely unrelated to the market price for capital funds. Inventory holding costs must also take into account obselescence risks as well as the capacity and variable operating costs of storage facilities.

The unit costs of processing purchase orders may depend heavily on the volume of orders actually processed. Thus, a curious circular situation results in which the unit cost of ordering depends on the volume of ordering, but the volume of ordering depends on the unit cost that is used in the decision rules. In the case of finished or semi-finished material that is being ordered on the company's own manufacturing facilities, order costs must also take into account the effect of different order sizes on plant congestion, and is thus related to the whole production priority system.

If the model includes some consideration of stock shortages, measurement of the shortage cost offers even greater problems than the previous two. The strategic decision will take into consideration the outcome variables of the system which could include average inventory investment, number of orders placed per year, numbers of stock shortages per year, etc. What is required is some method of relating the alternative outcomes defined in the efficient surface to the overall objectives and restrictions with which the company operates. Fortunately, a mechanism exists in every company for carrying out complex analyses of this sort. This mechanism is in the mind of the decision maker himself. Feeney concludes, therefore, that in situations in which it is not possible by direct methods to obtain meaningful measures of the cost parameters contained in the decision rules, the strategic decision might best be made by confronting the executive with a picture of the efficient surface. The final selection of a point on the curve as a target for company inventory operations is a decision that he himself must make.

Feeney simulated the behaviour of inventory items selected randomly from a system, in order to derive a synthetic efficient surface. System data was computed to determine average usage, unit cost and lead time. A decision rule was formulated to decide when an order should be placed on each item and how much material should be ordered. The computer kept track of both actual usage and orders placed and maintained a running balance of stock on hand. Measurements were made simultaneously of the value of inventory investment, the number of orders issued and the number of shortage delays that resulted over the period studied; cost ratios were varied during the exercise.

The procedure was to select particular values for each pair of cost ratios, insert these values in the decision rules, and then simulate the behaviour of the inventory over a two year period. Figure 7 shows a lattice of points in the cost ratio space. Corresponding to each point studied the outcome was observed in terms of average inventory investment, the number of orders processed, and the number of shortage delays. In this way a group of points on the efficient surface of the outcome space was defined.



where

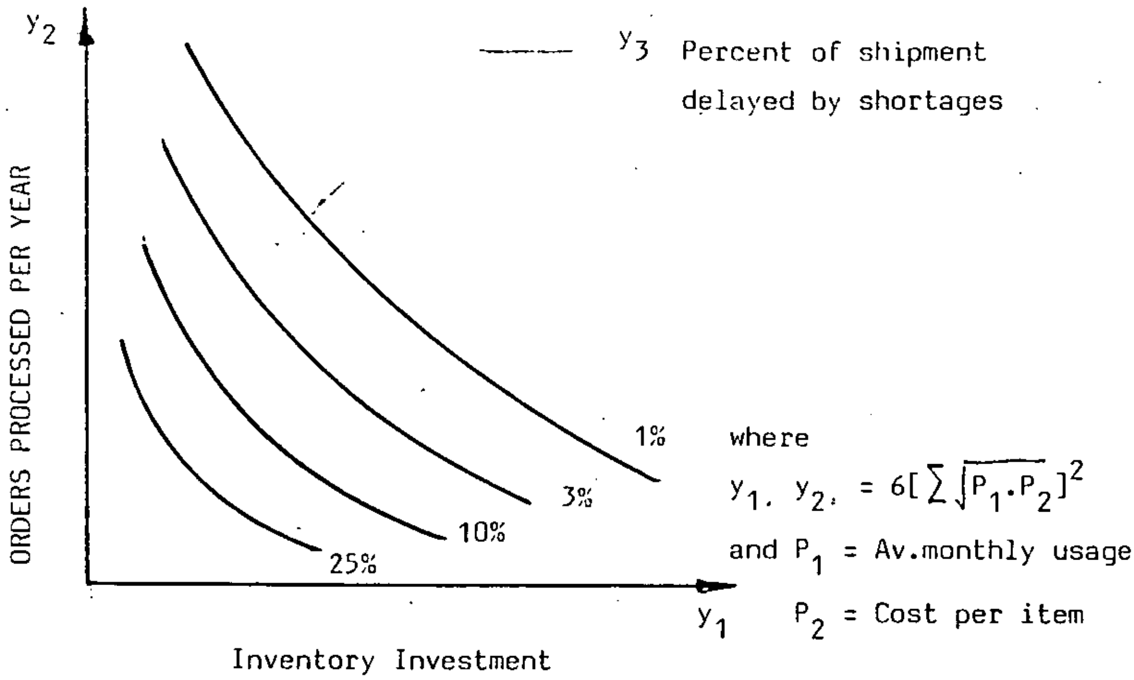
c_1 = the annual cost per £1 invested

c_2 = cost per order processed

c_3 = cost per shortage delay

FIG. 7

Figure 8 shows a complete picture of the outcome space as generalised from the particular values obtained. The curves show the entire range of alternative outcomes available to the company under the formulation that was employed. Any given point in this chart could be identified with a particular pair of cost ratios and could thus be attained through the decision rules. At this point it was possible to confront the principal executive involved with the entire range of alternatives available so that a decision could be made on inventory control operations which best related the outcome of these operations to the overall objectives of the company.



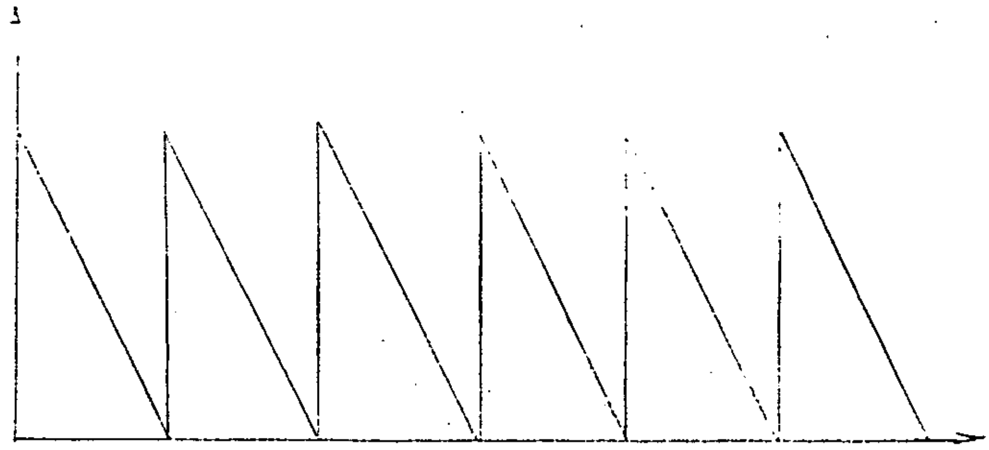
EFFICIENT SURFACE

FIG. 8

6.3 Parent/Subordinate Stock Relationship

Brown [10] states that in a time-phased planning system it is possible to plan to receive a lot of material just at the time a substantial part of that lot is consumed into the assembly of a parent item. In that case the lot size for the subordinate material should be an integral multiple of the lot size for the parent (assuming the material has only one use). When lower level inventory items are depleted by eratic demands, a large demand may be followed by several known periods of inactivity. In such a situation it makes no sense to immediately replenish the stock which would involve extra carrying costs. Figure 9 shows how multi-level lot sizes can create 'lumpy demands' at lower inventory levels.

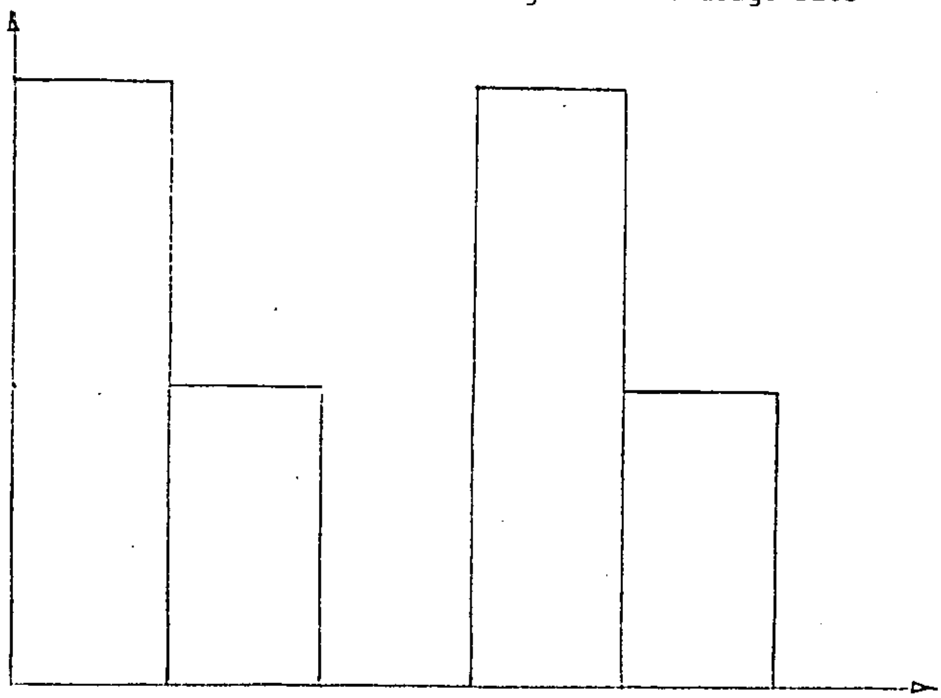
Stock Level



Time

Parent Stock - showing constant usage rate

Stock Level



Time

Subordinate stock - showing 'lumpy' demand due to lot sizes

FIG. 9

Brown derives lot sizes for multi-stage requirements using a modified EOQ formula. The equation (1) below shows the total annual cost expression for the lots of two items. The lot quantity for the subordinate is substituted as a multiple of the lot quantity for the parent which gives an expression for the economic parent lot quantity in equation (2). The effective set-up cost is the parent set-up plus a fraction of the set-up for the subordinate.

Similarly, the effective unit cost is the sum of the costs of the two items.

The ratio between the lots is given in equation (3). The procedure is first to use equation (3) to find the multiple k; round it to an integer (at least 1); substitute into equation (2) to find the parent lot quantity; finally, set the subordinate lot quantity as k times the parent lot quantity.

EQUATION (1) Total annual cost = $(S_s D/Q_s) + \frac{1}{2} Q_s C_s I + (S_p D/Q_p) + \frac{1}{2} Q_p C_p I$

let $Q_s = k Q_p$

EQUATION (2) $$Qp = \sqrt{\frac{2(S_p + S_s/k) D}{I(C_p + k C_s)}}$$

EQUATION (3) $$k = \sqrt{S_s C_p / S_p C_s}$$

where D = demand per year

S = set-up cost

C = unit cost per piece

I = carrying charge per year

Q = lot size

Subscripts p = parent item

s = subordinate item

Application: (a) find multiple k, round to an integer

(b) solve equation (2) for parent lot Q_p

(c) subordinate lot $Q_s = k Q_p$

New [45] is critical of the application of the lot sizing techniques which are based solely on economic performance or computational efficiency. New points out the problems involved in applying such techniques to systems where lot sizing is carried out at more than one level, and considers the problems are sufficient to question the whole concept of economic models and economic comparisons of performance, and offers some alternatives for examination.

New's attention is focused on the ordering or set-up cost and the unit variable cost in the multi-level context. In the heuristic presented the effects of using the 'added value' batch formula or the 'full cost' batch formula demonstrated that the relationship between the subordinate lot size and the parent lot size varies considerably with an adverse effect on the inventory total cost.

New concludes that there are enough weaknesses in the basic philosophy attached to the setting of economic parameters, even without multi-level problems. Perhaps more important is the fact that making such a choice may overlook other alternatives. One such alternative considers the effect on manufacturing capacity when lot sizes are changed.

6.4 Lot Size and Resource Availability

New [46], in an article entitled 'Matching Batch Sizes to Machine Shop Capabilities : An Example in Production Scheduling', presented a new practical approach to the lot size problem. New considers that :

(i) Batch sizes cannot be considered independently of lead time

(ii) the constant batch size approach based on the assumption of a continuous demand is totally inappropriate when applied to discrete period planning; and

(iii) the decisions concerned with any single part number interact strongly with similar decisions for other parts and this interaction should be considered in the decisions themselves.

The principles of the heuristic developed are very simple; first a 'reasonable' batch size based on economics is determined. Checks are then made to see that the batches, when actually issued, will not upset the operations of the shop. The first of these checks is to compare the slack time for a batch with the expected queueing time in the shop. See Figure 10 for explanation.

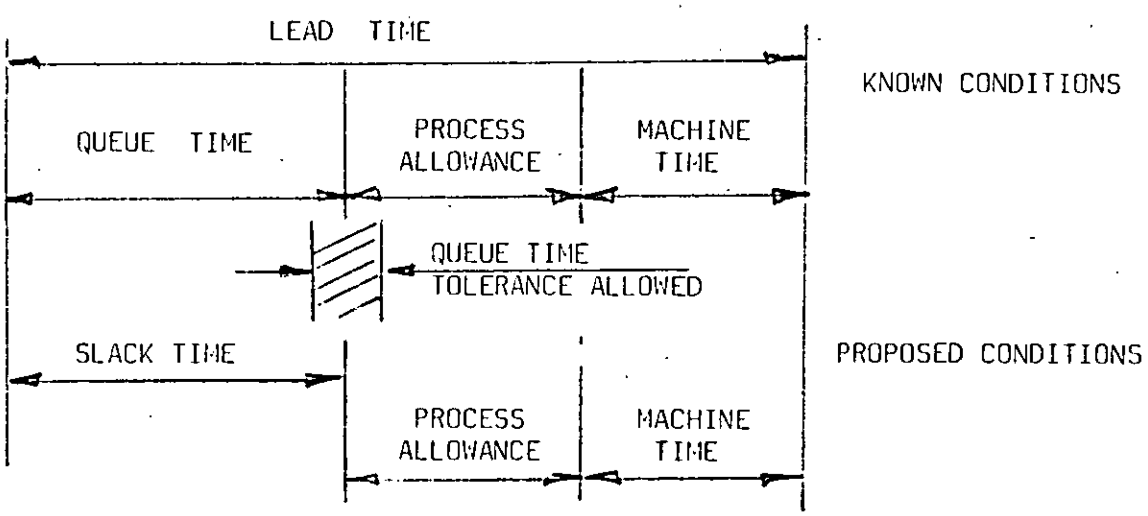


FIG. 10

If the slack time is within the queue time tolerance zone the associated batch size is acceptable. If the slack time is less than the minimum queue time, then the batch size should be reduced until an acceptable queue time is reached or the batch size must queue jump, i.e. the total lead time for the work is reduced. Should the slack time be greater than the maximum queue time, then the batch size is too small and may be increased.

New calls this approach the 'Slack Time Launching Rule" (SLR). When the control of input to a shop is a priority order based on the slack calculations, then a first-in-first-out (FIFO) sequencing system can be used.

However, in certain circumstances the FIFO system will never maintain relative priorities correctly. These are :

(a) The due dates or quantities required can alter significantly after launching.
(b) Individual machine group capacities can be reduced for time periods which represent a significant proportion of the average lead time for jobs.
(c) "Rush order" due to scrap, shortages, urgent requests, etc. represent a substantial proportion of the total load.

When such conditions prevail it will be necessary to resort to some other priority measure. One adaptive sequencing rule is 'least slack time per remaining operation' (LSOP).

A simulation model was developed which linked the launching of batches with their sequencing through a shop. Comparative results were achieved for two sequencing rules :

(a) FIFO
(b) LSOP

and two launching rules :

(a) existing constant batch quantity system with constant lead times, and batches normally based on simple EBQ model calculations
(b) the slack time launching rule (SLR) system.

Due date performance is shown in Table 1 and other results are shown in Table 2 for the LSOP sequencing rule.

Queue Sequencing rule	Launch rule	Lateness	
		Mean (time units late)	Standard deviation
FIFO	EBQ	20	30
	SLR	17	20
LSOP	EBQ	12.4	7.9
	SLR	4.3	5.3

TABLE 1 COMPARATIVE PERFORMANCE TO DUE DATES

Criteria	Result of using SLR instead of EBQ
Work-in-process inventory	Down 18%
Mean time batch is in shop	Down 20%
No. of batches launched	Down 20%
Machining time/(total involvement time)	Down 1%

TABLE 2 OTHER PERFORMANCE MEASURES

The comparative results shown indicate the considerable gains to be made from the use of the SLR system, particularly when it is linked to a continuing sequencing system based on a similar rule. However, even if no control is exercised other than at input, the gains are significant : a 15 percent decrease in mean lateness and a 33 percent decrease in the standard deviation of lateness.

6.5 Flow Control Ordering Systems

Burbidge [14] states that there are two types of ordering systems:

(1) Stock control ordering systems in which the release of purchase or manufacturing orders is controlled by the level of stocks in Stores. The primary aim of the system is to maintain stocks to satisfy the demand made on them.

(2) Flow control ordering systems in which the prime aim is to

provide the components needed to complete specific programmes of known, or forecast sales. Orders are based on 'explosions' from these programmes.

Burbidge considers the stock control ordering systems are inefficient and unstable, particularly when they are used for ordering direct materials for the manufacture of standard assembled products. Furthermore, Burbidge considers that most of the companies at present using stock control for standard assembled products could substantially increase their profitability by changing to a "flow control" ordering system. However, in spite of the disadvantages of stock control, the system may be efficiently used when the following conditions prevail -

1) Usage rate is even and known
2) The lead time is short
3) Receipts are in full batch quantities
4) Issues are in small quantities
5) The unit value is small

In situations where the above conditions are satisfied there should be little problem of stock control, hence the system will not be pursued further. The flow control ordering system, in contrast, would appear to offer certain practical advantages when applied to the needs in a manufacturing environment, which are not characterised by the above conditions.

Flow control ordering systems can be divided into two categories :

(i) Single cycle systems - orders are released together in product sets, on a series of common due dates, for completion by a series of common due dates. Batch sizes may vary each order period to meet changing demand.

(ii) Multi cycle systems - each item has its own special ordering cycle and is ordered independently of any other required items. Batch sizes are fixed with the time varying between order periods to allow for changing demand.

Burbidge highlights one special advantage of single cycle systems when applied to cyclic planning. It is possible with this system, when making standard products, to establish standard load charts which can be used repeatedly, period after period.

The relationship between ordering cycles for the different components in production at the same time has an important effect on the characteristics of material flow. Because all components for a product are ordered together and processed in a single cycle, further orders for these components will be released with each cycle 'in phase'. This condition allows easy scheduling as opposed to the difficulties encountered when products in the multi cycle system are out of phase and cyclic planning is not possible.

Burbidge [15] notes that over most of the quantity range changes in average batch quantity generally have an insignificant effect on total cost, and that a change from multi-phase to single-phase ordering can itself lead to substantial cost reductions. Ordering should be in balanced product sets, and the best batch quantity is the smallest.

Burbidge [16] favours the Period Batch Control approach to inventory control which is a single-cycle flow control system. In real life conditions in industry, new short term sales and production programmes must be planned at regular intervals, progressively throughout the year. Each short term sales programme should cover a cycle starting only a short period ahead. These conditions are necessary because it is impossible, particularly in multi-product batch production, to make accurate forecasts of future product sales by type for long periods ahead. Re-casting the short term programme at regular intervals makes it possible to follow changes in market demand without accumulating stocks of unsaleable products and without leaving part finished work standing idle in the factory.

It is not uncommon in industry today, when using multi-cycle systems, to have a throughput time of six months, and a six month lead time for ordering materials. The sales programme for each cycle must be issued at least one year before the start of the cycle. All industrial experience shows that it is impossible to obtain accurate forecasts consistently for such long periods ahead. To make the system work, both the throughput and lead times must be reduced.

Burbidge states that throughput times can be greatly reduced by the introduction of single-cycle ordering, and further reductions can be made by introducing group technology to simplify the material flow system. Purchase lead times can be reduced by separating shop ordering from purchase ordering.

Cycle periods of four weeks are usual for fairly complex products; periods of one and two weeks have been successful for simple products. Prior to the start of a cycle a programme meeting approves the next short term sales programme. The meeting decides the 'Minimum Make Quantity', which is the sales required, less stock, for each product. If the MMQ is less than capacity some of the most popular product lines are made for stock, or capacity is reduced. If the MMQ is more than the capacity, the capacity is increased, initially by additional sub-contracting or overtime, or delivery times are extended. The following advantages are claimed with the application of Period Batch Control -

1) The system can follow changes in market demand, without waste. The progressive issue of 13 new, short term programmes during the year, makes possible the frequent revision of forecasts.

2) The system can operate efficiently with a low investment in stocks and with a high rate of stock turnover.

3) Because all parts are ordered in product sets, materials obsolescence is eliminated.

4) Because all parts are made in product sets and only those products required for despatch in the forecast period must be included in the programme, the system is ideal for products with seasonal sales.

5) The system produces predictable, small variations in both stocks and the load on the component processing departments.

6) Because large numbers of parts are ordered together on each ordering day, savings in setting time and an increase in capacity can be obtained, using the tooling family method.

J. Duff [23] made the following observations on economic batch sizes. Batch sizes and lead times are mathematically inter-related. Duff considered a simple shaft with one turning operation and one drilling operation. Each turning operation is completed on the whole batch before drilling commences; should the economic batch size be infinitely large, the second operation is never started. Conversely, should the batch size be one component, then as soon as it is turned it passes to the drilling operation while a second component starts its turning operation. This simple demonstration emphasises the relationship of lead time to batch size and vice versa.

If a manufacturing facility is constrained by time which will not allow for normal lead time production, then the batch size can be modified to suit the time available. Conversely, if the batch size is fixed in relation to a delivery quantity and the batch is required to pass through a manufacturing facility, then the time taken for the batch to pass through the facility is fixed and all the progress chasers in the world will not shorten the cycle.

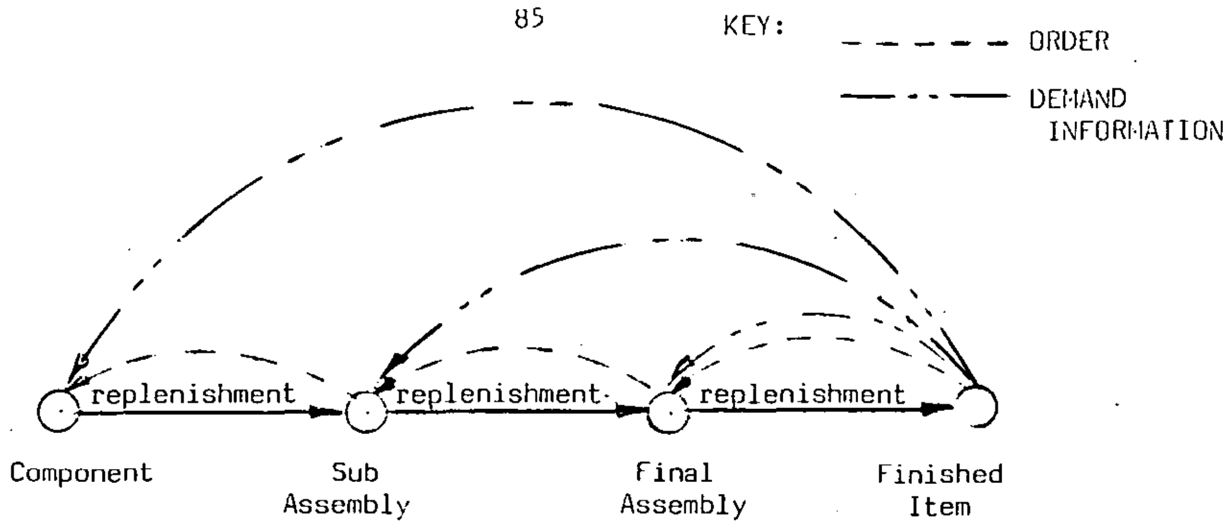
The advantages of splitting batches are well recognised. However, the temptation to do so is generally resisted, particularly in organisations where the geographical location of facilities make it difficult to monitor the progress of work. In Duff's example, should the lathe and drilling machine be positioned adjacent to one another, there would be no advantage, if the drill is available, to wait for the completion of the turned batch before commencing drilling. The intermittent process would be transformed into a continuous process.

This logic highlights the advantages to be obtained with Group Technology; manufacturing batch sizes can be at a minimum level, work-in-process can be drastically reduced, together with manufacturing lead times. The control of a product manufactured in such a system is made easier. Collectively, these advantages should ensure better customer service with a reduction in manufacturing costs.

6.6 Base Stock System

The distinction between the 'push' and 'pull' inventory systems has been made elsewhere in this thesis. The 'pull' system is generally regarded as informal. However, the 'pull' system can be used for formal inventory control as described by Dr. George E. Kimball [39] in his Base-Stock system.

In the base stock system, when the order for an item is placed against any inventory, it is filled from the inventory providing the level is not zero. If the inventory is zero or insufficient to meet the order the outstanding order quantity is placed in a back-order file, to be filled when sufficient inventory arrives. In any event, a manufacturing order is immediately placed with the preceding manufacturing station to replenish the items which have been consumed. The manufacturing station, in turn, immediately places an order for the required raw materials against the preceding inventory; as soon as the order is filled it proceeds to operate on it to produce the required items. In this way, an order against the last inventory for a finished item is immediately transmitted all the way back along the line to all manufacturing stations, each of which meets the requirements. This transmission of orders for finished items into production orders is called explosion; the idea of transmission back along the line step by step, is merely a conceptual one. Each manufacturing station makes replenishments based on actual finished item demand rather than a replenishment order from the next higher level. The instantaneous communication of finished item requirements to all levels of inventory, helps to overcome the fluctuation of demand as recognised by Forrester [28] in his study of "Industrial Dynamics". Figure 11 shows how the finished items demand information should be communicated to all inventory holding points.



INFORMATION AND STOCK FLOW IN A BASE STOCK SYSTEM

FIG. 11

This base stock system is ideal for a continuous production environment but could result in large in-process stock levels and 'frustrated' scheduling, if applied to an intermittent system.

Kimura and Terada [40], employed by the Toyota Motor Co. Ltd., considered the design and analysis of a pull system applied to a multi stage production system. They consider the conventional push system applied to production control has inherent problems which increase with the increase in the size of the system. The following problems are identified -

a) When drastic changes in demand or snags in production happen, it is virtually impossible to renew the production plan for each process. Therefore it is likely that such difficulties cause excess inventory or even dead stock.

b) It is practically impossible for production control staff to scrutinize all the situations related to production rate and inventory level. Hence, a production plan must have excess safety stock.

c) Improvement with regard to lot size and timing of processing could not progress, because it is cumbersome to compute optimal production plans in detail.

The pull system may solve such problems; improvements should be achieved providing that it is possible in a simple and dependable manner to replenish items, at the rate that the succeeding process has consumed them.

Kimura and Terada state the following aims of their pull system :-
In multi stage production processes, including outside suppliers:

(1) To prevent transmission of amplified fluctuations of demand or production volume of a succeeding process to the preceding process.
(2) To minimise the fluctuation of in-process inventory so as to simplify inventory control.
(3) To raise the level of shop floor control through de-centralisation: to give shop supervisors a role of production control as well as inventory control.

The Toyota Motor Co. Ltd., have applied the pull system which the Western world have named "The Kanban System" and give a loose translation to the word Kanban as 'just in time'. The system is designed so that materials, parts and components are produced or delivered just before they are needed. Kanban is the name of the 'ticket' or 'tag' which is used to communicate the requirements between processes.

Kimura and Terada, in comparing the push system with their research findings of the pull system, acknowledge the experimental results of the push system which have been found by Tanka and Tabe [64].

Figures 12 and 13 illustrate the comparisons. The conclusions from these experiments are :

(1) In the case of the pull system, the size of the order unit has much importance. In cases where the size is small compared with the production quantity level, production fluctuations will not be amplified in the preceding stage. Amplification will be brought about when the size is rather large, although, in this case also, the amplification is not further magnified in preceding stages.

(2) In the case of the push system, amplification of production and inventory fluctuations occur under the influence of errors in forecasting. As far as amplification is concerned, the choice between push and pull systems is determined by the degree of errors in forecasts.

(3) The other factor in the system parameters of the pull system, which affect the amplification ratio, is the lead time from the moment when a Kanban is removed from a container to the moment when production of the stage is completed. The longer the lead time, the larger becomes the amplification ratio.

The 'Kanban System' would appear to be an extremely simple procedure to follow, and if the Japanese manufacturing results are an indication of the credibility of the system, then serious consideration must be given to adopting the approach. Perhaps one becomes cynical about the re-invention of an old concept.

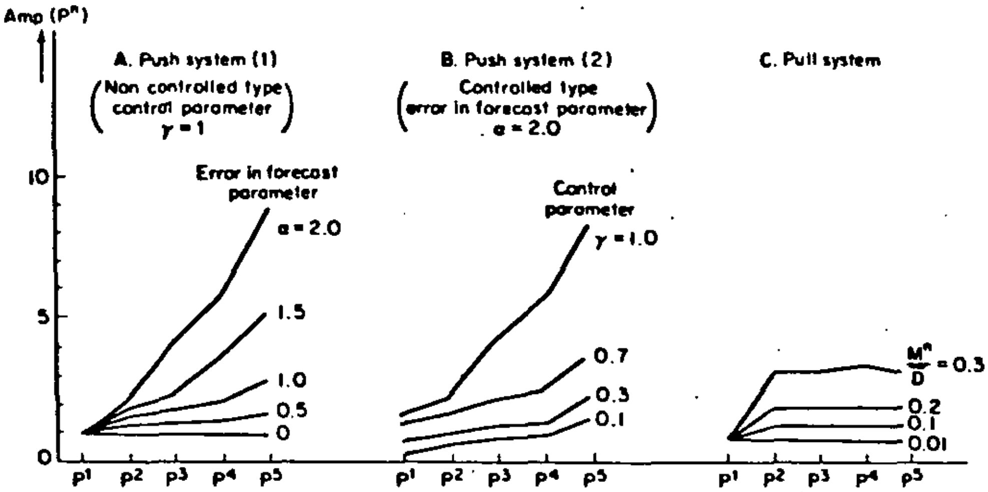


Figure 12 Amplification rate of production fluctuation.

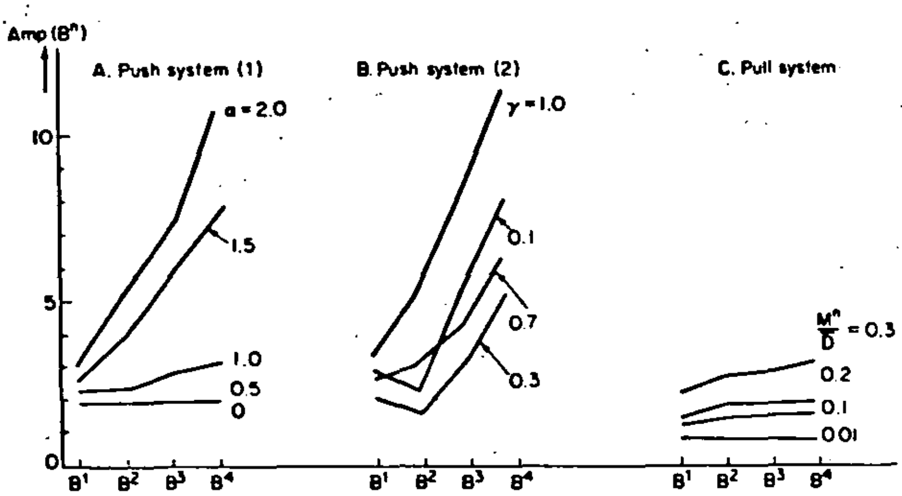


Figure 13 Amplification rate of inventory fluctuation.

Hayes [35] wrote an article following his visits to several Japanese factories. The conclusion drawn from the visit was that "no exotic gimmickery, only deliberate attention to the humdrum details of operations management. No secret formulas, only painstaking sensitivity to the strategic implications of those operational details. Nothing earth-shaking, only a reminder of what good manufacturing management has always been - and of what American managers used to know". Starr [62] made the following comment on the above conclusion : "Managers would like to think that the solutions to their productivity problem is that simple, but critical changes have occurred that make the return to the way things were, invalid. These changes include enlarged markets with increasing volume, new controls derived from computer based information systems, new products embodying major technological innovations, and new process technologies.

Plans are hidden from observers. Certainly, the economies of scale for large batch volumes can be ignored if set-up costs are reduced, but how is this done ? Innovative process technologies are responsible. They necessitate attention to integrating product line and process designs.

Perhaps the Japanese would like us to believe in simple solutions like going back to what we used to know; meanwhile, they are preparing for the next generation of what can be done."

6.7 Lot Sizes in a M.R.P. System

Biggs et al [8] state "there has been limited research developing or determining efficient heuristic decision rules for coping with the recurring lot sizing problems in an M.R.P. system."

The M.R.P. system uses the master production schedule to identify planned order releases for the necessary production items. However, the mechanics simply generate a set of net requirements that must be met if the master production schedule is maintained. The production schedule thus generated may be considered incomplete because M.R.P. has no built-in method considering economies of scale, such as combining the net requirements of more than one period so lots can share equipment set-up costs. Orlicky [50] also notes that an M.R.P. system is insensitive to system capacity. This means that the decision maker still needs a lot-sizing rule unless he wants to use the net requirements schedule of the M.R.P. as his lot sizes.

The lot-size decision is made difficult, particularly with a fluctuating demand for the end product. It is not always desirable even if possible, to compensate for a fluctuating demand by holding excess levels of stock or by smoothing out the production rate. When these techniques can not be employed a company manufacturing items in lot-sizes has the following choices.

(i) adjusting the lot-size to meet the change in demand

(ii) keep the lot-size constant and adjust the timing of lot-size replenishment.

(iii) a combination of lot-size adjustment and replenishment timing.

W.A. Ruch [59] introduced a moving EOQ concept which he applied to a varying demand situation. The technique was compared on a cost basis with the following alternative systems :

1) Traditional EOQ - a standard EOQ formula was employed using the average demand for 12 periods. Whenever the net requirements exceeded the EOQ, enough items were ordered to fill that requirement. Unused items were carried in stock for use in subsequent periods.

2) Periodic Order Quantity - using basic data an economic order interval was determined and an order placed to cover the needs for all periods within that interval.

3) Part Period Balancing - this algorithm orders materials for successive periods in the future until the carrying cost is equal to the order cost.

4) Wagner-Whitin Algorithm - an application of dynamic programming, the algorithm examines every feasible ordering possibility and selects the one with the least cost. It is, thus, the best possible answer to the problem. Ruch uses the results as the standard by which other methods are measured.

   Although the Wagner-Whitin procedure has been available for some time, it has not found widespread use because of computational complexities. Carlson et al [17] question the appropriateness of the Wagner-Whitin algorithm on other grounds. First, in any system with an hierarchical assembly structure, the algorithm guarantees optimal order of production lot sizes only for each level of the hierarchy treated independently. The levels of the hierarchy are not independent; in fact the essence of an M.R.P. system is to exploit the dependence among levels in projecting future requirements. The second way in which the real world differs from the model involves the use of up-dated information in re-scheduling. The model assumes that demand data remains unchanged during the planning horizon. In fact, most schedules are developed on a rolling basis; as each period passes, a new period is appended to the horizon. This can cause changes in the optimal lot sizes, though obviously having a much greater effect on the later periods in the horizon than the earlier periods.

5) Silver-Mead Algorithm - this algorithm is similar to the Part Period Balancing in that it evaluates at each decision point whether to place an order for 1, 2, 3 ... periods into the future. The heuristic is simple to use and yields comparatively economical decisions.

The moving EOQ example given by Ruch is shown in Fig. 14 The traditional EOQ attempts to use the same order quantity throughout the time horizon, based on the overall average demand, the moving EOQ takes on a shorter time horizon and thus adjusts to radical changes in requirements.

Ruch used demand patterns for his study published in previous work by Berry [5] (see Table 3) He considered the use of the same assumptions and the same data would permit a better comparison of the various algorithms considered. Using demand pattern 4 from Berry's data sets, an EOQ was calculated based on the average of the first three months' demand. This yielded an EOQ of 59. Since all the material for a period must be on hand at the beginning of the period, there is no reason to carry over part of a period's requirements. Therefore, rather than ordering 59 units, the order is placed to cover as many periods as are necessary to approximate the EOQ. In this case, 55 units will cover periods 1 to 4.

MOVING EOQ EXAMPLE

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
Requirement	10	10	15	20	70	180	250	270	230	40	0	10
Moving EOQ	59				224		274	232	164	71		
Quantity Ordered	55				250		250	270	230	50		
Beginning Inventory	55	45	35	20	250	180	250	270	230	50	10	10
Ending Inventory	43	35	20	0	180	0	0	0	0	10	10	0

FIG. 14

An order must be placed in period 5, so an EOQ is calculated based on the average demand for periods 5, 6 and 7. The EOQ of 224 is best approximated by ordering 250 units to cover periods 5 and 6. In period 7 the process continues. (See calculations Page 94).

The results of Ruch's research are shown in Table 4 . The comparison shows the Wagner-Whitin algorithm is always the lowest cost and that the traditional EOQ performs very poorly by comparison. The

Period	Data Sets 1	2	3	4
1	92	80	50	10
2	92	100	80	10
3	92	125	180	15
4	92	100	80	20
5	92	50	0	70
6	92	50	0	180
7	92	100	180	250
8	92	125	150	270
9	92	125	10	230
10	92	100	100	40
11	92	50	180	0
12	93	100	95	10
	1105	1105	1105	1105
Standard Deviation	0	27.0	66.1	130.0
Coefficient of Variation	0	.293	.718	1.410

DEMAND PATTERNS

TABLE 3

Order Cost	Procedure	Cost — Demand Pattern 1	2	3	4
	Traditional EOQ	5120	5435	4951	4865
	Periodic Order Qty.	4011	4055	3615	3945
$300	Part-Period Balancing	4011	4055	3545	3485
	Wagner-Whitin	4011	4055	3435	3245
	Silver-Meal	4011	4055	3554	3245
	Moving EOQ	4011	4105	3635	3505
	Traditional EOQ	3859	4873	3747	3799
	Periodic Order Qty.	3447	3491	3145	3381
$206	Part-Period Balancing	3577	3359	2933	2787
	Wagner-Whitin	3447	3353	2871	2681
	Silver-Meal	3447	3541	2871	2701
	Moving EOQ	3447	3359	3113	2941

TOTAL INVENTORY COST PERFORMANCE

TABLE 4

CALCULATIONS

Using $EOQ = \sqrt{\frac{2DS}{I}}$ where D = demand

S = order cost ($300)

I = inventory carrying rate :

($2 per unit per period)

Demand over first 3 periods (1 - 3) = 35 units

$$\therefore \quad EOQ = \sqrt{\frac{2 \times 35 \times 300}{2 \times 3}}$$

$$= 59 \text{ Units}$$

But period 1 to 4 requires 55 units,
hence order 55 units to cover periods 1 to 4

Next 3 periods 5 - 7 = 500 units

$$\therefore \quad EOQ = \sqrt{\frac{2 \times 500 \times 300}{2 \times 3}}$$

$$= 224 \text{ Units}$$

Periods 5 and 6 require 250 units
hence order 250 units to cover period 5 and 6

Next 3 periods 7 to 9 require 750 units

$$\therefore \quad EOQ = \sqrt{\frac{2 \times 750 \times 300}{2 \times 3}}$$

$$= 274 \text{ Units}$$

But period 7 requires 250 units
hence order 250 units to cover period 7 only.

Next 3 periods 8 to 10 require 540 units

$$\therefore \quad EOQ = \sqrt{\frac{2 \times 540 \times 300}{2 \times 3}}$$

$$= 232 \text{ Units}$$

But period 8 requires 270 units
hence order 270 units to cover period 8 only etc. etc.

other methods, however, show varying degrees of 'fit' or approximation to the Wagner-Whitin algorithm. It is clear that no method, apart from the Wagner-Whitin algorithm, is best under all circumstances.

6.8 System Nervousness

One problem associated with M.R.P. is called 'system nervousness'. This is caused by the hierarchical nature of M.R.P. where the demand at high levels in the production process as shown by the master production schedule, is exploded to determine lower level item demand. Consequently, changes in demand at the higher level will cascade down through each level of the bill of material amplifying the original change, particularly when a lot-sizing approach is adopted.

An alternative approach to those listed previously, which uses a constant order quantity and adjusts the timing, has been proposed by Hoskin [37]. The method claims to overcome the problem of random oversells and undersells that happen with any forecast. The oversells and undersells cause re-schedules of both open and planned orders, resulting in the master schedule constantly 'churning', giving very different priorities with each re-planning; the problem, known as system nervousness, compounds as the re-schedules pass through each level of the Bills of Material. Hoskin's time-phased order point removes this nervousness from the system; he considers it advantageous to generate a plan that is stable, yet contains the priority information so necessary to maintain customer service. Stability is an important component on two counts : first, for realistic capacity planning, and second, because it is almost impossible to schedule lower level parts to hit a moving target. The stability is absolutely critical over cumulative lead time for an item, and certainly desirable beyond that. Hoskin states that his solution to overcome the nervousness averages out the oversells and undersells to equal the forecast. No forecast runs to a dead flat average; demand can be very 'lumpy' in the short term but results in fairly predictable demand over the longer term. The problem is two-fold : how do you keep producing while an item is going through a temporary lull in sales, yet not distort your priorities ? If the forecast is true, then carry forward the pluses and minuses until they even out. The cumulative adjustment is carried forward indefinitely and action taken only when a permanent skew to one side of the forecast is apparent. When a dramatic undersell or oversell occurs an exception message would be triggered off, calling for a re-schedule. The advantage of this approach is that it does not change the order quantity; the plan calls for an adjustment in timing not quantity. The damping of the master schedule nervousness, however helpful in scheduling, must not be allowed to mask a trend or forecast error. This problem can be readily solved by calculating the ratio of the cumulative adjustment to the average forecast: the adjustment tracking signal.

EXAMPLE:

Adjustment to gross requirements (unsold forecast carried forward)	=	+ 600
Forecast quantity per week	=	100
Ratio + 600 ÷ 100 Signifying 6.0 weeks undersell	=	+ 6.0

This ratio is a simple forecast tracking signal, and can be reported on when it exceeds pre-set bounds, unless there are unusual market circumstances. An item with a 6.0 week undersell should certainly have its forecast revised downward.

Through the tracking signal, undersell and oversell priority information can reach the master scheduler. Underselling items are re-scheduled, which provides vacant capacity for other, needed materials, otherwise they represent an undesirable inventory commitment. Oversells may be accompanied by a backlog and by standard exception messages to 're-schedule in'. If vacant capacity is present, this may be used to build some of the oversell items early to absorb the capacity and maintain customer service.

The logic of Hoskin's approach lies in the principle of 'management by exception'. A good forecast is one in which actual demand follows the predicted distribution around an average demand. The approach allows for a normal distribution of demand around the forecast, but gives a warning when serious deviations take place. This is more logical than having the master scheduler wade through pages of exceptions, sorting out the trivial from the important, and trying to re-schedule fast enough to keep up with an item whose demand may normally vary over plus or minus several weeks average forecast. The concept of having undersold or oversold 'x' weeks of forecast is readily understood by people who can deal with it without a statistical background.

Steele's article [63] on the causes of the nervous system states that "dynamic lot-sizing of intermediate levels can be nearly disastrous for a system where nervousness is present. The dynamic lot-sizing may actually amplify upper-level twitches as they are passed to low levels". However, the impact of lot-sizing nervousness can be dampened by using a fixed order quantity as the lot size. All the advantages of discrete lot-sizing are lost, but if changes are occurring frequently, orders matched exactly to requirements would be temporary anyway, and the resulting stability could be invaluable.

The fixed order quantity does not pass quantity changes through to subordinate items. Only the timing of the second and subsequent planned orders is changed. Since the vast number of 'B' and 'C' items would have long order cycles, there would be time to react to changes in the second order. The 'A' items could then receive maximum attention. Steele also comments on the possible short-comings of the fixed order concept in that it does not automatically change once set. It may become an uneconomical quantity under a revised master schedule, or it may over order a part with declining usage; then it becomes necessary to review at regular intervals the appropriateness of the lot-size.

Wight [74] states that dynamic lot-sizing techniques can be used effectively, but it is very important to recognise that when they are used in higher levels of the product structure they can cause added expense at the lower levels. A good rule to follow : never change a lot-size inside the cumulative lead time for lower levels in the product structure without first checking to see what the effect will be.

The preceding arguments in favour of using a fixed order quantity and varying the period of time bwtween orders to meet a fluctuating demand pattern within agreed limits, would appear promising.

The next hurdle, if a fixed order quantity is to be used in an inventory system, is to adopt a technique which arrives at a suitable lot-size. The choice of the most appropriate lot-size can have a dramatic effect on the control of inventory, perhaps even more so when the quantity will not change over a period of time. There are many different approaches, some previously mentioned, which claim to provide an optimal lot-size. The yardstick used to measure optimality changes depending on the data used; it is necessary to carefully consider which data to accept for use in calculating the lot size.

Wight [74] says, traditionally, production and inventory management books cover lot-sizing and forecasting in the early chapters. Wight purposely moved them to the sixth section - out of the mainstream - because experience has shown that operations can be improved dramatically even if very approximate lot-sizes are used and even if no new forecasting techniques are introduced.

The writer accepts Wight's view on forecasting but not his statement on lot-sizing. The lot-size quantity and its application can have a significant effect on operations. Part of this thesis will consider this aspect.

6.9 Flexible Manufacturing Systems

The economic approach to batch sizes is further challenged with the introduction of Flexible Manufacturing Systems. A special report in The Production Engineer (April 1980) outlines a series of machine types with various degrees of flexibility, in order to produce a series of parts belonging to the same family, or to different families, with low, or even non-existent, changeover tool and fixture times.

The manufacturer of the machine lines presently supplies lines which can handle 'closed' families of parts; these are similar and have in common the type of machining and the shape, they differ only in dimensions.

The 'open' family of parts has different shapes and dimensions, but a common type of machining with maximum dimensions constrained within a certain volume.

The Flexible Manufacturing System consists of integrated systems of numerical controlled machines and automated transfer devices managed by 'real time' process computers for 'open' families of parts. These systems have been used for production rates varying from 5 to 40 parts an hour with a variety of parts ranging from 3 to 35 different types.

Wood [77] states "There is no future for manufacturing industry other than the Flexible Manufacturing System, one which can mass produce batch quantities as small as one saleable unit".

Before such a situation can become a reality in the majority of industries, the Production Engineer must first change his philosophy from 'floor-to-floor' to 'door-to-door'. Jobbing or batch industry, with shop layouts based on like processes and like skills, as against process flow lines, immediately imposes a financial penalty on the organisation in terms of working capital. The cost of putting material on the shop floor, picking it up again, moving it and the necessity of indicating priorities in a never ending queue, far outweighs the cost of converting material into finished goods.

The jobbing or batch plant mainly devotes all its energy into optimising the plant and labour resources at the expense of the material; yet the material is the only resource for which the organisation will ultimately receive cash. Can any business, therefore, afford to optimise labour and plant at the expense of work-in-process ?

The optimisation of labour and plant resources is the objective in the organisation, which will achieve the best floor-to-floor time. In all the effort to devise economic batch quantities, there is the assumption that all machining belongs to the machine shop and likewise for press shop and assembly. This is because the cost system is based on material, labour and overheads. It is a system based on 'how we make things', where the real truth of profitability is more bound up in 'when things are made'.

If Management could change their emphasis from "why is that machine not working" to "why is that component not being worked on", there would be a different outlook on the shop floor.

Manufacturing industry has only been able to respond to a volatile market by using large stocks of machined parts or sub-assemblies, which require a heavy commitment of capital. G.E.C. Machines is carrying out a study into providing a facility which can serve its customers within 24 hours or within machining time, plus 5 percent, from raw material to finished component.

Companies not employing these latest techniques will have problems gaining orders against a competitor's short lead time supply, and with competitive pricing of the product. When the manufacturing costs can be dramatically cut with the reduction of work-in-process, inevitably the producer will reflect the savings in the price of the product.

CHAPTER VII

SAFETY STOCK

7.1 Need for Safety Stock

Safety stocks may be associated with all materials needed in the manufacture of a product or indeed with the product itself. In a continuous system safety stock will normally be considered in the raw material, service parts and finished good state. In an intermittent system additional safety stock may be required at each stage of production. Company policy should determine at which stage or stages in the production cycle safety stock should be held.

Safety stocks constitute one of the major means of dealing with the uncertainties associated with variations in demand and lead time. They are amounts of inventory held in excess of regular usage quantities in order to provide specified levels of protection against stockout.

If demand for the product is known precisely, it is feasible, though not necessarily economical, to produce the product to meet the demand exactly. In the usual case, however, demand is not completely known and a safety stock must, therefore, be maintained to absorb variation. Increases in demand due to promotional campaigns or seasonal demands can be planned for. Such seasonal inventory allows a gradual build up of stock in anticipation of this higher demand and permits a more stable employment level with lower capital investment. Other factors which need to be taken into consideration when determining safety stock levels, may include :

1) Forecast error

By definition, forecasts are probably going to be wrong to some degree, consequently, when inventory levels are initially set by a forecast, it will be necessary to make adjustments when forecast requirements and actual requirements do not agree.

2) Exposures to Stockout

Stockout occurs when the new supply does not arrive in time to satisfy demand. The new supply may be provided either from an outside supplier or from a process within the organisation. An internal stockout could be the result of machine breakdown, equipment malfunctions or tool failure. The stockout risk is greatest just before the new supply of material is received; consequently, the number of stockout risks is a function of the number of re-orders per year.

3) Lead Time

Forecast error increases as lead time increases, thus items with long lead times will need higher levels of safety stock than items with short lead times, but the relationship is not linear. If, for example, an item with a four week lead time requires two weeks safety stock, an item with an eight week lead time will not require four weeks of safety stock; the reason being that it is most unlikely that a two week period with a high level demand will be followed immediately by another two week period with a high level of demand.

4. Service Level Requirement

It is usually desirable to have a higher service level for some items in inventory than for others. A company offering replacement parts would be more concerned about having spares in stock at all times when the demand for such parts is frequent and/or an alternative supplier is readily available. While the company may well stock less popular parts, these parts will usually have a lower level of customer service.

5. Planning and Control

In any manufacturing or supply industry, the quality of planning and control can vary considerably. When the organisation has good systems which react to changing demands, then in general terms the amount of safety stock held will be minimised for a stated service level. Alternatively, an organisation which reacts slowly to changing demands will need to carry an extra stock if they wish to match this service level.

7.2 Safety Stock and Lead Time

Tersine [65] considers that the traditional inventory models such as economic order quantity, economic production quantity and economic order interval, frequently do not account for risk and uncertainty in their formulation; they assume many of the variables are known. For example, the following assumptions are generally made in the inventory management theory of the 1950s and 1960s.

(i) lead time is fixed and known; or
(ii) lead time is an independent variable;
(iii) the due date originally assigned will not change.

The theoreticians then concerned themselves with the computation of safety stock which would compensate precisely for the variation in demand over lead time or the interacting independent variation in lead time demand.

It is now recognised that lead time is highly variable and that it may be shortened or lengthened by the expediting or de-expediting of the informal system. The great breakthrough in thinking has been to recognise that in most cases, lead time is a reasonably controllable variable, and that priorities must be revised continually to respond to changing needs. In the real world :

(i) lead time is usually variable based on the priority a job is assigned in the queue;

(ii) lead time is usually dependent, at least relatively, upon need;

(iii) with the advent of M.R.P. priorities can be updated regularly, based on needs.

However, risk and uncertainty enter the inventory analysis through many variables, but the most prevalent are the variations in demand and lead time; these two variables may be absorbed by the provision of safety stock.

Safety stock has two basic effects on a firm's costs - it will decrease the cost of stockouts and increase the cost of holding stock.

Safety stocks would be unnecessary if an organisation were willing and able to make its customers wait until the items they wanted could be ordered or until their orders could be scheduled into production conveniently. These additional stocks are part of a business philosophy of serving customers needs without delay because of its implications on the long term effectiveness of an organisation.

It would be fallacious to believe that safety stock is maintained for altruistic purposes. Stockout conditions result in external and internal shortages. External shortages can result in backorder costs, present a profit loss when a sale is not achieved, and endanger future profits with the erosion of goodwill. Internal shortages can result in lost production with idle men and machines and a delay in completion date with a possible cost penalty.

Stockout cost is usually the most difficult inventory cost to ascertain. This difficulty is compounded by the uncertainty of future customer actions on additional purchases. In one situation a sale is not lost, but only delayed a few days in shipment. Typically, a company would institute an emergency expediting order to get the item as a backorder. The backorder results in expediting costs, handling costs, and frequently, shipping and packaging costs. In another situation, the sale is lost. The stockout cost in this situation ranges between the profit loss on the sale to some unspecified loss of goodwill cost.

A stockout cost can result in an extremely high cost if it is a raw material for a production line that cannot function without the material and consequently is shut down. It can be seen that a stockout cost can vary considerably for different items based on customer use or internal use.

There is no universally accepted formula or rigid procedure to follow in determining safety stock. The calculations of different methods available are based on the amount of information known to management. The information is usually based on demand, lead time and stockout costs. The information known about these variables determines the complexity of the calculations. If demand and lead time are constant, there will be no need for safety stock since inventory decisions are made under certainty. Under these conditions the inventory will be at zero level when the replenishment order is received. This is a case of perfect knowledge of demand and lead time, which is probably an unrealistic situation. Theories on the levels of safety stock may consider the following situations :

(i) variable demand and constant lead time
(ii) constant demand and variable lead time, or
(iii) variable demand and variable lead time.

In a 'live' situation both demand and lead time would normally vary, which increases the complexity of the problem. A joint probability distribution of demand during the replenishment period can be developed. The range of the joint probability distribution would be from the level indicated by the product of the smallest demand multiplied by the shortest lead time to the level indicated by the product of the largest demand multiplied by the longest lead time.

An alternative approach to the joint probability method for determining safety stock when demand and lead time are variable. is by Monte Carlo Simulation [12]. To carry out such a simulation the data is required on both the demand and lead time distribution. With this distribution data, demand would be simulated during lead time and safety stock levels obtained for various risk levels of stock out. It is then necessary for management to select a particular risk level by applying the corresponding level of safety stock. When the distribution is approximately normal the cost, in extra stock to achieve a corresponding level of customer service, rises rapidly as 100 per cent service level is sought. See Fig. 15 [34].

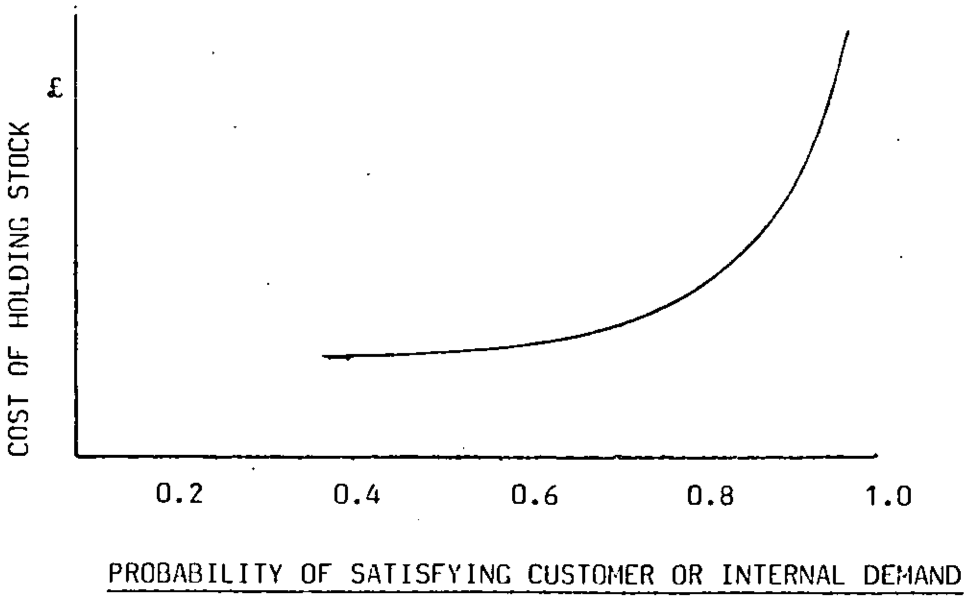


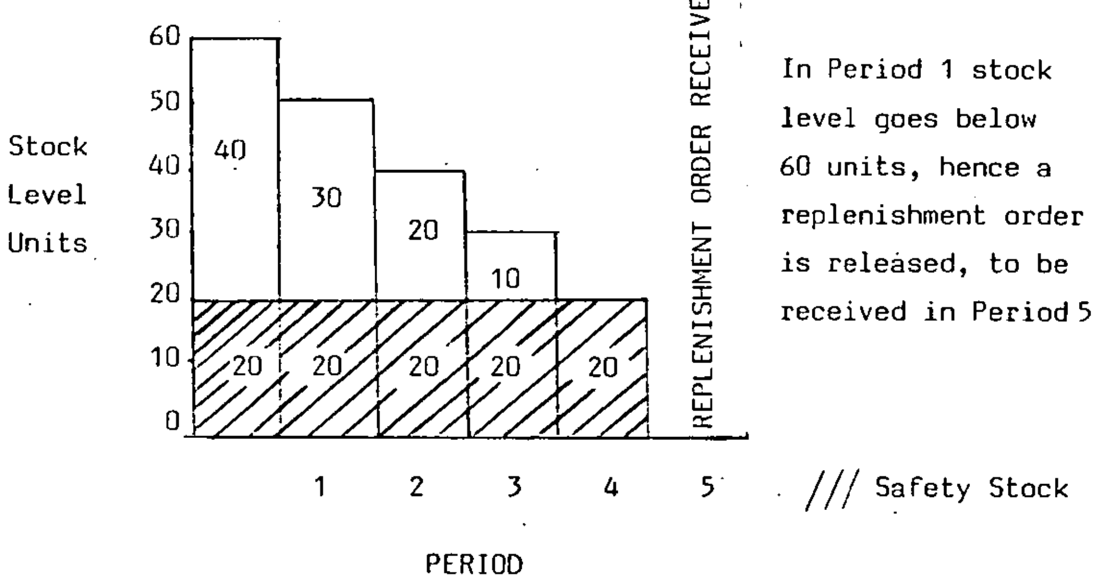
FIG. 15

7.3 Safety Stock and M.R.P.

When an M.R.P. system is used, safety stock at the item level is not normally planned [49]. It is, however, planned under a time phased order point. In either case the M.R.P..logic common to both types of system, tends to defeat the purpose of safety stock by preventing it from ever actually being used if the system can help it. The following example, comparing the order point logic to the M.R.P. logic, will help demonstrate this point.

An item has a planned lead time of four weeks, the forecasted demand during the lead time is 40 units; assume a safety stock of 20 units. The order point is, therefore, 60 units, i.e. when the stock levels fall below 60 units a replenishment order is released.

PERIOD		1	2	3	4
FORECAST		10	10	10	10

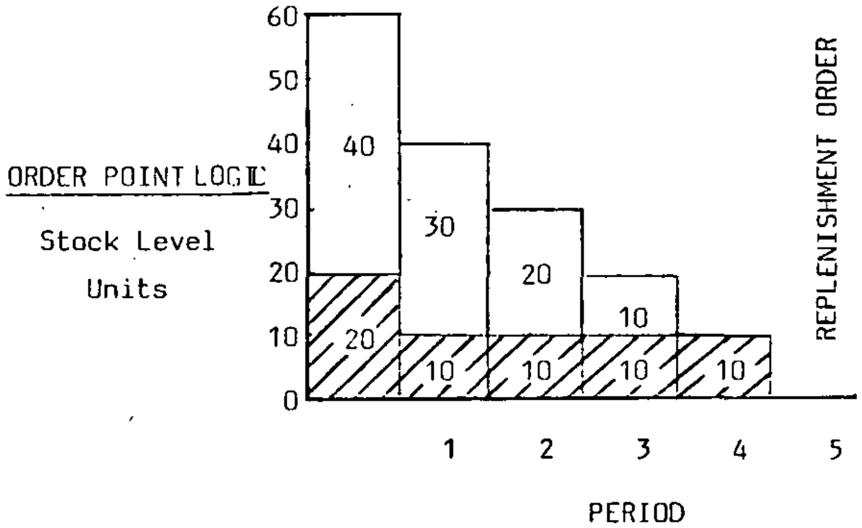


IMPLICATIONS OF SAFETY STOCK

FIG. 16

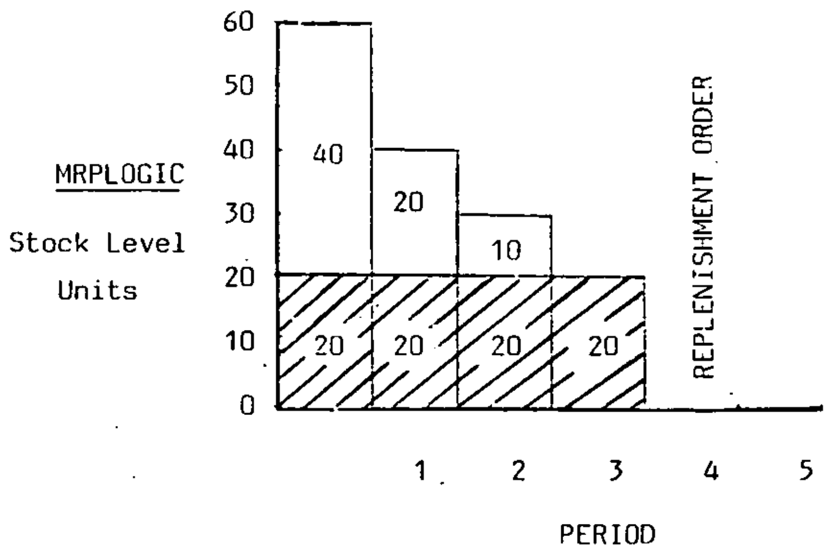
In Figure 17 the order point reaction to an excess in demand is shown; the excess in demand is thought of as having been met from safety stock and the timing of the replenishment order remains unchanged.

PERIOD		1	2	3	4	
FORECAST		10	10	10	10	
ACTUAL		20				



SAFETY STOCK : DEMAND EXCEEDS FORECAST IN FIRST PERIOD

FIG. 17



SAFETY STOCK : DEMAND EXCEEDS FORECAST IN FIRST PERIOD

FIG. 18

With M.R.P. logic, the system has reacted to the excess demand by moving the due date for receiving the order one period forward, which keeps the safety stock at the original 20 units. (See Fig. 18)

It is seen that the time phased order point approach attempts to keep the safety stock level intact by re-scheduling the replenishment order. Provided that the re-scheduled order can be satisfied, safety stock proves to be dormant inventory that could be drastically reduced, if not entirely eliminated. There are, however, instances in the time phased order point system when it is desirable to hold safety stock, for example.

(i) at the master production schedule : In the M.R.P. system, uncertainty only exists at the master production schedule level; the exception to this is when spares are provided for lower level parts. Safety stock, where required, should, therefore, be provided through the master production schedule for the end items. The explosion of the master production schedule will automatically include safety stock at lower levels of the structure and prevent duplication of such stock.

(ii) For protection against demand variation over the shortest minimum lead time. The manipulation of lead times has been previously identified as a means of meeting surges in demand. The shortening of lead times will eventually reach a point where no further reduction would be economically viable. Safety stock for independent demand items could be computed statistically to protect against demand variations over this shortest lead time.

Berry and Whybark [7] disagree with Orlicky in his views on setting safety stock at the end product level to compensate for fluctuation in demand. They consider this recommendation implies that there will be no uncertainty in the manufacturing process, such as shrinkage, spoilage or equipment failure, and that lead time flexibility will be able to accommodate master schedule changes that are projected down to the lower level components. In fact, there will be uncertainties in the process, and changes in the master schedule may give rise to substantial expediting costs to meet changing priorities.

Mayer [43] states that the economic lot size approach to inventory control is complicated by the fact that an inter-relationship exists between the order quantity and the safety stock. In the determination of the amount of safety stock that should be carried, it should first be recognised that the order point approach to inventory control is able to make an automatic partial adjustment for unexpected increases in demand. If the actual consumption rate proves to be greater than the expected rate, the re-order point will be reached earlier and a new order will be placed sooner than it otherwise would. However, once the re-order point is reached and the order for replenishment stock is placed, the firm can do nothing but wait until the new lot is received. If an unexpectedly high demand occurs during this period, the firm will either have to draw on any safety stock available or fail to satisfy the additional demand.

The importance of this lies in the fact that it focuses attention on when the risk of an out-of-stock condition arises. The out-of-stock crisis is only when the re-order point is reached. Further, because an increase in lot size results in a reduction in the number of orders placed per year, and, therefore, in the number of times the re-order point is reached per year, it becomes apparent that the frequency of the risk of a stock out is affected by the lot size, suggesting that the problem of safety stock determination cannot be considered independently of the lot size.

7.4 Safety Stock v Safety Lead Time

There are two basic methods of providing safety stock to reduce the effects of uncertainty that can arise in an M.R.P. system. One method is to specify a quantity of safety stock in much the same manner as the statistical inventory control technique. The second method, safety lead time, plans order releases earlier than indicated by the requirements plan and schedules their receipts earlier than the required period. Both approaches produce an increase in inventory levels to provide a buffer against uncertainty but the techniques operate quite differently.

Whybark and Williams [72] have studied the use of safety stocks and safety lead times in order to determine the most effective technique under various types of operating conditions. They classified uncertainty into four different categories, according to the source of the uncertainty (demand or supply), and the type of uncertainty (timing or quantity) as shown in Fig. 19.

TYPE OF UNCERTAINTY	SOURCES	
	DEMAND	SUPPLY
Timing	Requirements shift from one period to another	Orders not received when scheduled
Quantity	Requirements for more or less than planned	Orders received for more or less than planned

CATEGORIES OF UNCERTAINTY IN M.R.P. SYSTEM

FIG. 19

Their hypothesis was that there would be preference for either safety lead time or safety stock under each category of uncertainty. Using a simulation model, they tested the effect of the two strategies on service levels and average inventory levels under widely varying conditions. Their conclusions were that under conditions of uncertainty in timing (either in the arrival of supplies or demands), safety lead time is preferred. Conversely, when either the quantity demanded or supplied was uncertain, safety stock was the preferred technique.

7.5 Customer Service

Plossl [52] suggests that safety stock levels can be set by trial and error methods. After excess inventories have been eliminated, professional practitioners avoid the general question "What customer service level should we maintain ?" and develop instead trade-off curves. Using such data, management can determine that "to improve service levels by X percent will require Y additional cost in safety stock investment". Using these and similar approaches for other functional classes of inventory, some companies will soon be able to determine how much inventory they really should have.

Corke [19] also considers the use of exchange curves in setting the levels of safety stock; the level of service being maintained by the order frequency in relationship to the usage value classification. The 'C' category items should be ordered less frequently, thus reducing the proportion of time at which there is any risk of stock-out. A high service level is likely to be met from stock with no need to carry safety stock. An exchange curve can be constructed for each category of stock as shown in Fig. 20 A decision might be taken to operate at a higher service level on the 'C' items than on the 'A' items. This will reduce the delays caused by stock-outs on perhaps half the items, but incur only a very small additional investment.

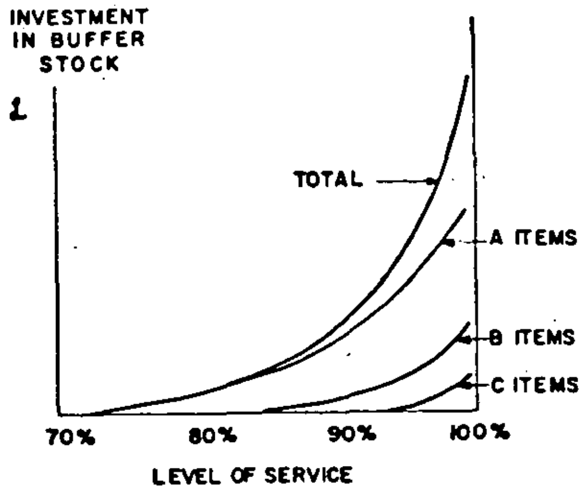


Figure 20 Usual spread of investment over A, B and C items

New[47] states that the service level approach for setting safety stock has certain limitations and considers four ways of defining service -

1) PERCENTAGE OF DEMAND SATISFIED IMMEDIATELY FROM STOCK

If, over a period of time, requests are made for 1,000 items and 960 items are actually supplied 'off the shelf', this will represent a 96% satisfaction of demand immediately.

While this measure is valid in a situation where a large number of customers and/or volume of sales are involved, it does not differentiate between the situations in which :

(a) the 40 items short were all for the same order, i.e. one stock-out; or

(b) the 40 items were for 40 different customers, i.e. forty stock-outs.

This service level approach takes no account of the frequency of stock-outs, and the effect of these on goodwill.

2) NUMBER OF ORDER CYCLE SHORTAGES

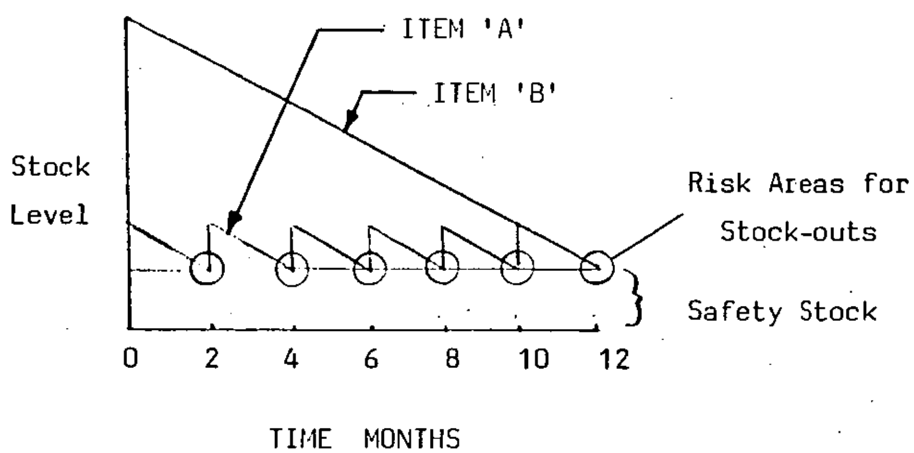
Service is defined as the percentage of replenishment cycles in which no shortages occur. If there is stock remaining in store when a new order arrives, then no shortage has occurred and if this happens 90 times out of 100 cycles, then a 90% service level is achieved.

This service measure introduces some uncertainties in that it does not consider the extent of the stock-out on a given cycle. A more serious disadvantage occurs because the method does not consider the time aspect of the shortages for items which have different replenishment cycles. The same percentage 'service level' implies quite different levels of customer satisfaction. For example, suppose a 90% service level is applied to two items:

Item A which has a two month replenishment cycle, and

Item B which has a one year replenishment cycle.

Item A enters the 'risk area' for a stock-out six times per year, while for item B only once per year (See Fig. 21).



RISK AREAS DURING REPLENISHMENT PERIODS

FIG. 21

3) PART-PERIODS OF SHORTAGE

The measure is obtained by the product of the number of parts and the number of periods for which the parts are out of stock. Having the items out of stock for two periods results in 2 x 10 = 20 part periods of shortage.

The service level is defined as the number of part-periods of stock shortage acceptable during a particular time period, for example 200 item-weeks per year. In most cases the cost of not having a part available will increase with time. This measure does, however, imply an equivalence between ten items for one period and one item for ten periods. The number of customer orders which might be affected is not considered, neither are the possible effects on assembly plans for internally required parts.

4) MORE SOPHISTICATED TECHNIQUES

Many companies develop composite methods involving elements of all these measures since each has its own merits. One simple extension to the part-periods of shortage approach is to give a measure of the proportion of demand filled within successive time periods, for example -

Proportion of demand filled from stocks	88.6 %
" " " " within one week	92.2 %
" " " " " two weeks	94.5 %
" " " " " three weeks	98.8 %
" " " " " four weeks	100.00%

which indicates the proportion of demand which was delayed and by how much.

Brown [9] carried out a number of experiments in which the exchange curve technique was used to decide which of two safety stock rules gave the better results. One rule specifies that a fraction of demand shall be met from stock of each item, the fraction ranging from 85% to 99.5%. The other rule uses a safety stock level computed to minimise the total cost of carrying safety stock (at 24%) and of expediting whenever there will be a shortage. Because of the difficulty in measuring the cost of a single expediting action, a policy variable ranging from $1 to $128 per shortage was used in the experiment. Fig. 22 shows the relationship of the two safety stock rules. From the curves it is clear that the expediting rule is better than the equal-service rule, provided we are interested in the number of potential shortage occurrences. However, should the measure of service be changed to consider the value of back orders, that is the seriousness of the shortages rather than simply the number of occurrences, using the same inventory of stocked items we now have a reversal of the previous result as shown in Fig. 23.

These two examples demonstrate the need for management to make a strategic decision; which of the two rules should be used ? It depends considerably on whether the relevent measure of customer service is the number or the seriousness of shortages. If potential shortages can be averted by expediting, then one rule is better, if the demand is simply back ordered when it cannot be met from stock, the other rule is better.

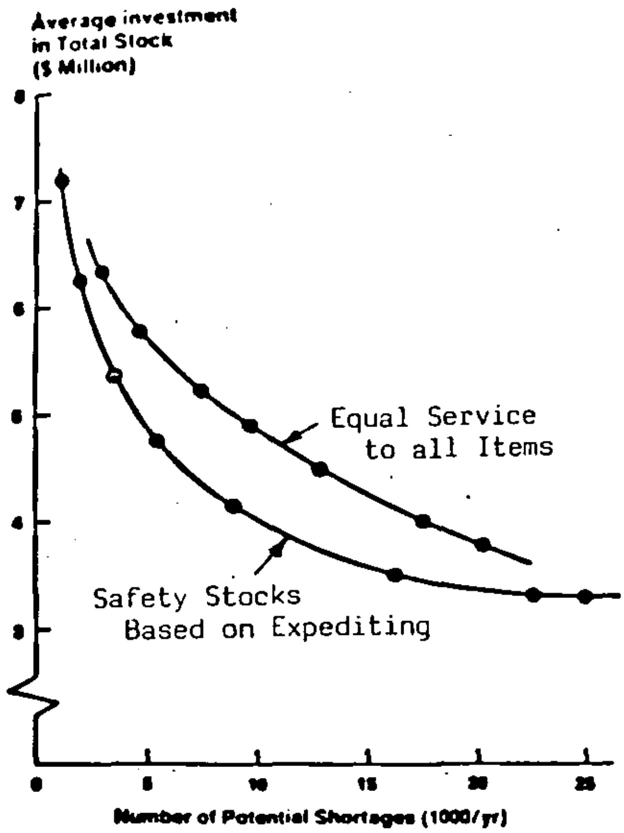

Average investment
in Total Stock
($ Million)
Equal Service
to all Items
Safety Stocks
Based on Expediting
Number of Potential Shortages (1000/yr)

FIG. 22

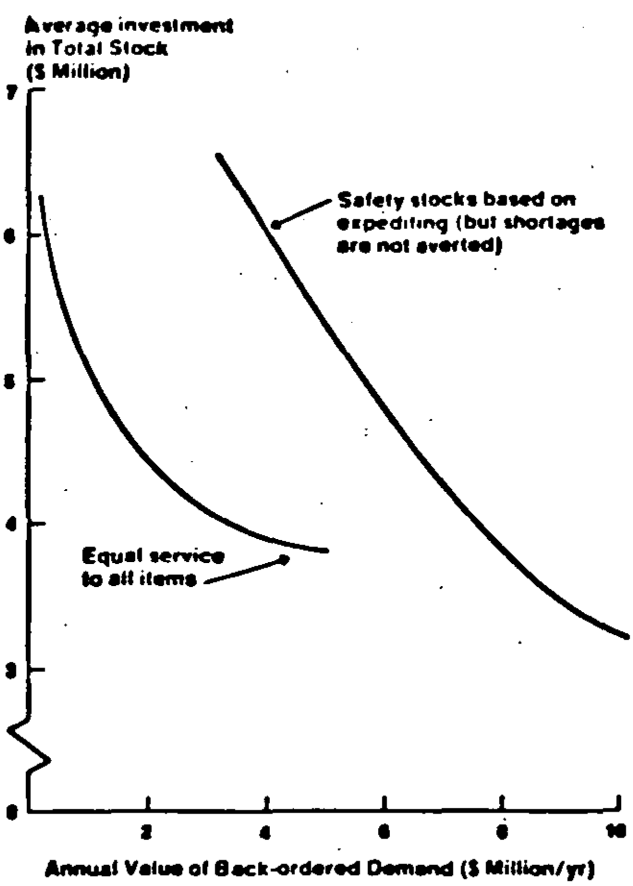

Average investment
in Total Stock
($ Million)
Safety stocks based on
expediting (but shortages
are not averted)
Equal service
to all items
Annual Value of Back-ordered Demand ($ Million/yr)

FIG. 23

Safety stock levels are normally calculated using an expected level of production. As production levels change there is a need to change the levels of safety stock. In all likelihood, safety stocks will increase to meet the needs of higher production, but it is doubtful if they will then be reduced in line with a long-term fall in production. It is necessary to review the allocation of safety stock regularly. Management can secure an overall control by calculating the total value of safety stock provision periodically, and then by selecting items at random, ensure that they comply with established policies.

Management should maximise the use of the cash available for safety stock by distributing it in such a manner that critical items have a preference over other items which results in a satisfactory product service level commensurate with company policy. It should be understood that all company products may not be awarded the same level of service and product service levels may change, depending on such factors as market requirements, product life cycle, cash flow etc. This, once again, emphasises the need for management to make considered policy decisions and be fully aware of the implications of these decisions on the service levels which can only be maintained with the associated levels of inventory.

CHAPTER VIII

THEORY/PRACTICE RELATIONSHIP

Grayson [32] states that "Management Science has now become arcane or nearly so; a bridge must be built between it and the real world of the executive. Management science has grown so remote from and unmindful of the conditions of 'live' management that it has abdicated its usability. Managers for their part have become disillusioned by management science, and are now frequently unwilling to consider it seriously as a working tool for important problems."

Management and management scientists are operating as two separate cultures, each with its own goals, languages and methods. Effective co-operation, and even communication, between the two is minimal. There are, however, some management scientists who operate effectively in both cultures, but these are rare. Most management scientists are still thinking, writing and operating in a world that is far removed from the real world in which most managers operate. The scientists often describe and structure non-existant management problems, attack relatively minor problems with overkill tools, omit real variables from difficult problems, and build elegant models comprehensible to only their own colleagues.

Gregory et al [33] carried out an exploratory study of stock control in small firms. The objective of the study was to determine the following :

(i) do small batch manufacturing companies use the techniques illustrated in the textbooks ?

(ii) if not, are they aware of this body of knowledge ?

(iii) are the techniques appropriate for application in the companies studied ?

(iv) if they do not use them, what factors influence their stocking policies ?

The conclusion from the study showed that overall the knowledge amongst the practitioners of the textbook techniques was limited, and the only techniques used were simpler ones, such as the two bin system and the lot-for-lot system. The practitioner generally considered that the literature tended towards sophisticated solutions to simplified problems, whilst they were looking for relatively simple solutions to sophisticated problems.

The companies studied gave the impression that raw material stocking decisions were sometimes a straight forward matter involving basic arithmetic, and in other situations they involved highly intuitive, if not inspirational, decisions.

The application of standard stocking techniques to the companies studied is questionable in terms of relevance and potential benefits.

It might be considered that small companies, similar to the ones investigated, can operate successfully with intuitive and inspirational decisions . However, a large concern needs the co-ordination of a delegated management team. Co-ordination of dissimilar activities is normally conditioned by the application of decision parameters based on theoretical knowledge.

A comprehensive survey carried out by the University of Bradford and sponsored by the Institution of Industrial Managers [42] concerned itself with 'The Practice of Production Management in the U.K.' Selected findings from the survey are given in Appendix B

Preliminary results indicate that managers in U.K. owned companies make significantly less use of techniques that could help them reduce the load of routine tasks than do managers in foreign owned companies. Consequently, managers of U.K. owned companies have less time and other resources to concentrate on their more important tasks, resulting in a less efficient use of manufacturing facilities compared with their foreign counterparts.

Also significant is that the American owned companies exhibit a greater use of good management techniques compared with British firms of the same size and their manufacturing operations, even in this country, seem to be more efficient than ours.

Davis [20] presents a study of production and inventory techniques, past and present in the U.S.A. (see Appendix C for results). The summary of the findings show that an earlier report in 1966 [25] recognised a great untapped potential of theory which could be converted into practice, and predicted that the next survey would be largely a matter of measuring the higher levels of success practitioners would be achieving in applying scientific techniques. However, the 1973 results reveal not so much a closing of the gap in utilising scientific techniques in general, but a new gap appearing as further techniques are developed. The focus in the seven years since 1966 appears to have been towards the use of older, simpler (e.g. A.B.C., E.O.Q.) and newer, less mathematically sophisticated procedures (M.R.P., Capacity Requirements Planning). The use of the computer during the interval has undoubtly been a significant factor in the utilisation of the latter procedures, since many of these techniques depend upon the brute power of the computer for their effectiveness. Davis considers the overall picture of the study "is a field which exhibits some of the better aspects of maturity, including, but not necessarily limited to, the ability to distinguish between the charms of frivolous sophistication and the promise of less glamorous but perhaps more lasting attributes of simplicity and effectiveness."

The objective of this research is to attempt to bridge the gap in one particular case between the scientist and the manager. It is not intended to produce a solely academic solution and then search for a problem. Instead, a real industrial problem has been identified with the understanding that any solutions derived may not be so elegant as they might be, but they may be used.

During the literature survey associated with this thesis, it became apparent that Material Requirements Planning is a technique which offers many advantages to the manufacturing manager, particularly in the areas of inventory control and scheduling. The investigation considers the application of M.R.P. in the company reviewed, together with some of the basic needs of the system which may determine whether the technique would be successful or not.

The innate constraints of the company such as forecasting difficulties, random demand from customers with high variability and historically long lead times, present many difficulties. It is postulated that a certain degree of stability may be possible if a master production schedule can be derived which will minimise the effects of the constraints on the manufacturing facilities made available for production.

Other constraints which need to be considered when formulating a solution to the problem include the contractural agreement of delivery lead time between the manufacturer and the customer and the layout of the production facilities.

It is considered necessary to manufacture in batches at all levels of production and assembly, with the exception of the final assembly stage of the product. At this level it is more attractive to produce lot-for-lot to meet the final product special requirements.

No attempt will be made to re-organise the production layout. It is considered that such an approach is unlikely to have a dramatic effect on the efficiency of the existing manufacturing and assembly facilities.

Perhaps the most significant reason for resisting a revision of the production facility layout is the difficulty in optimising the layout of plant to meet the ever changing demand associated with intermittent production and a large variety of products.

PART II

CHAPTER IX

SELECTION OF A PRACTICAL SITUATION

9.1 Choice of Company

The objective of this research is to identify how production planning and control theory may be successfully applied in the practical situation. It is submitted that although there is a proliferation of research work which is directed at the improvement of production planning and control, there are nevertheless, many problems which remain in this area in industry. It may be that some research findings have little practical value, due to the basic assumptions made, and perhaps some of the theory may be considered to be too complicated by the practitioner, resulting in its rejection. Although the practitioner may not need to follow all the steps involved, if he does not have confidence in the applicability of the assumptions made and in the plausibility of the outcomes, he is unlikely to use research findings on a shop floor for which he is responsible. It is worth mentioning that technology has made some of the theoretical findings more attractive and the ever growing use of the computer in the field of production control is complementary to this observation.

To enable a realistic comparison to be made between the theory and practice of production control, a company has been selected which is considered typical of manufacturing organisations in a similar production environment. Further, the manufacture of a particular product is examined in depth, with the appropriate application of historical data made available by the company.

The company chosen for investigation is John Davis and Son (Derby) Ltd., a medium sized company employing 540 people. Davis is a principal subsidiary company of Doulton Engineering Holdings Ltd., which belongs to S. Pearson and Son P.L.C., the ultimate holding company. The Pearson organisation comprises four main divisions employing about thirty thousand people, their 1979 turnover being £484 million compared with a £7 million turnover of John Davis.

John Davis is one of the most widely known companies in the mining industry, tracing its ancestry back to the 18th century. The business stemmed from a family concern founded in Leeds in 1779, the company of John Davis and Son (Derby) Ltd., being established in 1828. The move to Derby coincided with the rapid growth of the Midlands mining industry, which was one of the most technically advanced industries of the day. Davis commenced production of a range of instruments for surveying and air measurement in mines and was one of the first manufacturers of the miners safety lamp invented by Sir Humphrey Davey.

Davis were quick to recognise the advantages of electricity and in 1899 the firm established an electricity generating station and began distributing electricity to a large number of organisations in Derby. The company's close association with the mining industry for more than a century, made it inevitable that they should pioneer the use of flameproof and intrinsically safe electrical apparatus in mines, in association with the Sheffield Safety in Mines Research Establishment. They manufactured electrical bells, relays, telephones and signal / devices which could be used without the risk of igniting methane gas.

Today Davis supply equipment to control, monitor and, if necessary, computerise a mine, including surface, shaft and all underground operations. They have an engineering team on call to travel to any part of the world to assist and advise in the planning of mine electrical and electronic applications and to install and commission the equipment. Davis satisfy approximately fifty per cent of the National Coal Board's needs for communication systems, the remaining share of the market being divided amongst four other manufacturers.

The experience gained by manufacturing equipment for use in inflammable atmospheres enabled the company to apply their highly specialised knowledge in other industries where similar explosion risks occur.

The Marketing department at John Davis is divided to serve two main market segments, namely Industrial and Mining. The manufacturing resources available within the company are evenly utilised in producing goods for each market segment.

9.2 The Production Department

The Production Department within the company is controlled by a Production Director who has the following managers reporting directly to him :

1) Production Service Manager
2) Production Planning Manager
3) Works Production Manager.

Production planning and control is the responsibility of the Production Planning Manager, who controls the Product Planning Section, Materials Management Section and the Buying Section, these sections being staffed by the following personnel :

Production Control;

- 1 Production controller
- 1 Production scheduler
- 4 Progress chasers
- 2 Administration clerks.

Stock Control;

- 1 Stock controller
- 3 Docket clerks
- 2 Administration clerks.

Warehouse Control;

1 Supervisor

1 Clerk

2 Customer liaison clerks

Purchasing;

1 Chief buyer

3 Assistant buyers

2 Progress chasers

2 Administration clerks

Stores;

1 Stores supervisor

1 Section head

1 Chief storekeeper.

9.3 Existing Computer Facilities

The company have an NCR 8250 computer which was initially installed for use by the accounting department. Production control currently have use of this computer but due to the problems of sharing this heavily loaded facility, and particularly when the accounting department have priority use of the service, it is now intended to purchase a new computer for use solely by the production control department.

The "DORIC" order processing and inventory control system is used on the computer. DORIC is designed to provide an inter-active, inter-related file, online, real-time material control and order processing system. The system may be considered as five sub-systems as follows :

1) Customer order entry and invoicing
2) Requirements explosion
3) Stock control
4) File entry
5) File maintenance.

Each sub-system manipulates the data held on three main files, namely ;

1) Inventory
2) Customer Orders
3) Material requirements.

Subsidiary information is held on other files ;

1) Product structure
2) Where used.

The files contain the following information ;

INVENTORY

1) Descriptive data of the part
2) Full cost and selling price
3) Statistical history
4) Stock control information.

CUSTOMERS ORDERS

1) Customer descriptive data
2) Data to enable use as sales ledger master file
3) Details of orders outstanding for each customer.

REQUIREMENTS

1) All outstanding requirements
2) All outstanding orders for an inventory item
3) Details of any planned production schedule for an inventory item.

The DORIC system would appear to have the ability to provide good information for use by production control; however, a manual card system is also in operation which appears to have priority over the computer. The warehouse and stores staff considers that the computer readouts are not up-to-date and therefore cannot be relied on. For example, stock used is not always deducted immediately from the computer file; in some instances it is only deducted when the order has been despatched. In the case of spares, these may not be deducted from the inventory file until the customer pays after the receipt of the goods.

At the beginning of the investigation it was acknowledged that the product structure file was not reliable due to two main reasons; the structure file could be modified at more than one source and wrong information was entered in the first instance.

9.4 Production Planning and Control within the Company

Each product requires a number of operations to be carried out on raw material in a pre-determined sequence which differs from product to product. An operation is carried out by a single specified facility and occupies that facility completely for a length of time.

Where there is more than one similar facility available, which is capable of performing an identical operation, the batch of items may be split to reduce the total batch lead time.

The amount of work which is dealt with by sub-contracting depends mainly on the input of orders to the company. The only area which is not dependent on order input is the production of plastic components.

The company has limited capacity and expertise in plastics; consequently 80% to 100% of this work is sub-contracted. Other areas where work is sub-contracted are :

		Capacity sub-contracted
1)	Fabrication	25 to 30%
2)	Machining	maximum 15%
3)	Assembly *	5%

* the assembly work contracted out is basic unskilled work carried out by local hospitals.

Bought out items may go directly into an assembly or may be operated on to suit a particular requirement. In some instances raw materials and bought out items will be consumed in the manufacture of different products, i.e. they are common usage component items.

To allow the Production Control Department to prepare for future consumer needs, a production programme is presented for a twelve month period January to December. The information provided on the programme is the result of product demand forecasts presented by the Mining Marketing Director and the Industrial Marketing Director. The Production Director has sole responsibility for the formulation of the production programme after receiving the two demand forecasts. The computer facility is not used to assist in forecasting future requirements.

The production programme is used by production control to project requirements for a three month period, taking into consideration any outstanding orders, new orders, current stock level, capacity and material shortages.

Weekly meetings are held between the Production Control Department and individual production departments. Outstanding orders are reviewed and priorities set for the following weeks production and material shortages listed for action.

Customer requirements which cannot be met from stock and in-plant orders for manufacture to stock are sent by production control in the form of a works order to each of the manufacturing departments concerned. The works order informs the manufacturing department of the product and the batch quantity required, the process routing, materials required (not including tools) and the start and finish dates. The start and finish dates are generally ignored, the actual loading on the shop floor being carried out by the supervisor who is guided by the availability of materials and priority decisions made at the weekly production meeting. A materials kitting list and material shortage sheet is sent to stores showing the requirement date of the materials listed.

At the beginning of this research the company would kit out the requirements of an order to identify whether there were any shortages or not. When shortages did occur the part kitted order was placed in a secondary storage area awaiting the arrival of the shortages. However, during the research the company modified the order kitting activity. Orders for major products are now vetted via the computer where a visual display shows whether a full complement of parts is available. Those parts available are allocated in the quantity required but not physically kitted; the kitting exercise is carried out just prior to the requirement of the parts in the works. Should any shortages, identified by the computer, not be available by the kitting date, the kitting procedure is delayed until the parts short are received. This method ensures that orders are not released to the Stores until all the material is available. It readily permits the de-allocation of parts should an order be cancelled or the re-allocation of parts should a high priority product requiring the same parts be needed immediately by production.

Shortages of parts are inevitable if the amount of cash available for stock is to be controlled at a reasonable level in relation to sales. The company's average yearly stock/sales relationships over a six year period are as follows :

1976	4.37
1977	3.79
1978	3.04
1979	3.81
1980	3.55
1981	3.54

The majority of shortages in the company are recognised as 'in-plant' shortages, i.e. parts which are manufactured in the company. On average each job kitted has 20 shortages, an overall shortage can be roughly divided into 80% in-plant and 20% suppliers.

The company operate an order point system for the control of stock using maximum and minimum levels of stock for the system parameters and replenishment of stock is stated in batch quantities. The maximum and minimum levels and replenishment batch quantities are set by estimation by the Production Control Department. The up-dating of stock is not initiated automatically by the computer. Stock levels of the investigated items frequently fell below the minimum set level for stock. It would appear that the company carries out a stock planning function but control is mainly achieved by expediting requirements, sometimes regardless of cost, to replenish depleted stock. Inevitably this type of control results in delays in satisfying customers' orders, causes disruptions and frustration in the manufacturing departments within the company and results in excess levels of work-in-process.

The company manufacture and assemble products, with the plant layout in the process format. The meaning of jobbing in this thesis will cover any manufacturing facility which has the following attributes.

The jobbing shop employs a variety of manufacturing resources which are used for processing raw material to produce a specified item.

The jobbing shop will also affect the assembly of items into sub-assemblies and the final assembly of the sub-assemblies into a saleable product; alternatively, certain items and sub-assemblies will be available for supply as customer spares.

The facilities are of various types which generally have a flexible processing capability. Each facility may exist on its own or may be a member of some generic group.

The production - inventory system may be classified as an intermittent system where manufacturing is geared to producing in batches. A second basis for classification depends on whether or not final products are held in inventory for immediate use or sale, or whether goods are produced only after a specific need for them has been established. This method of differentiating among systems addresses the issue of product positioning in terms of elapsed time between the receipt of a customer's order for a product and the manufacturer's delivery of that product to the customer. The product positioning decision is largely determined by the manufacturer's marketing policy regarding customer service and response time. Some factors which will influence this decision are competition, manufacturing lead time and product life cycle.

The stock record cards of the sub-assemblies investigated indicate that the company has no firm policy on product positioning.

9.5 A Product

The company manufacture approximately five hundred and fifty different products which require a varying amount of production capacity. There are approximately twelve thousand different parts held in stock to support the manufacture of products.

To assist in the selection of a product to investigate, a Pareto analysis was applied to actual customers' orders received at the company during a one month period. The company had previously carried out their own Pareto analysis of their products; the 'A' category products were named the 'top 35' by the company. The product chosen came under the 'A' classification in both surveys.

The product requires a total of five hundred and seventy six parts, these are presented in a 'bill of materials' which involves five levels of structure from product (level 1) to raw material.

The product selected is one supplied to the National Coal Board which is identified as a major customer of John Davis with fifty per cent of its mining communication needs being satisfied by the company. It is thought that an investigation of such a product will enable the findings to be associated with other industries and customers who have a similar relationship albeit not in the actual product.

A contractual agreement exists between the company and the National Coal Board which sets the price and supply lead time for each product but not the quantities. The agreement is reviewed annually.

Orders are received from the National Coal Board at random intervals and may be sent from a number of sources, e.g. central stores or an individual coal mine. Repeat orders are normal but the final configuration of the product can change. This encourages the manufacture of items and sub-assemblies in batches, leaving the final assembly of the product until an order is received stating the exact form in which the product is required. The supply lead time currently stipulated by the customer allows adequate time for the final assembly to take place.

Stock levels and usage of parts consumed in the manufacture of the product selected were collected as follows; stock record cards for level 2 requirements (items and sub-assemblies required for final assembly build) were investigated for all parts valued at £1 and over. It was considered that lower cost parts should be held in stock in quantity and controlled by a simple stock control system such as the two-bin method.

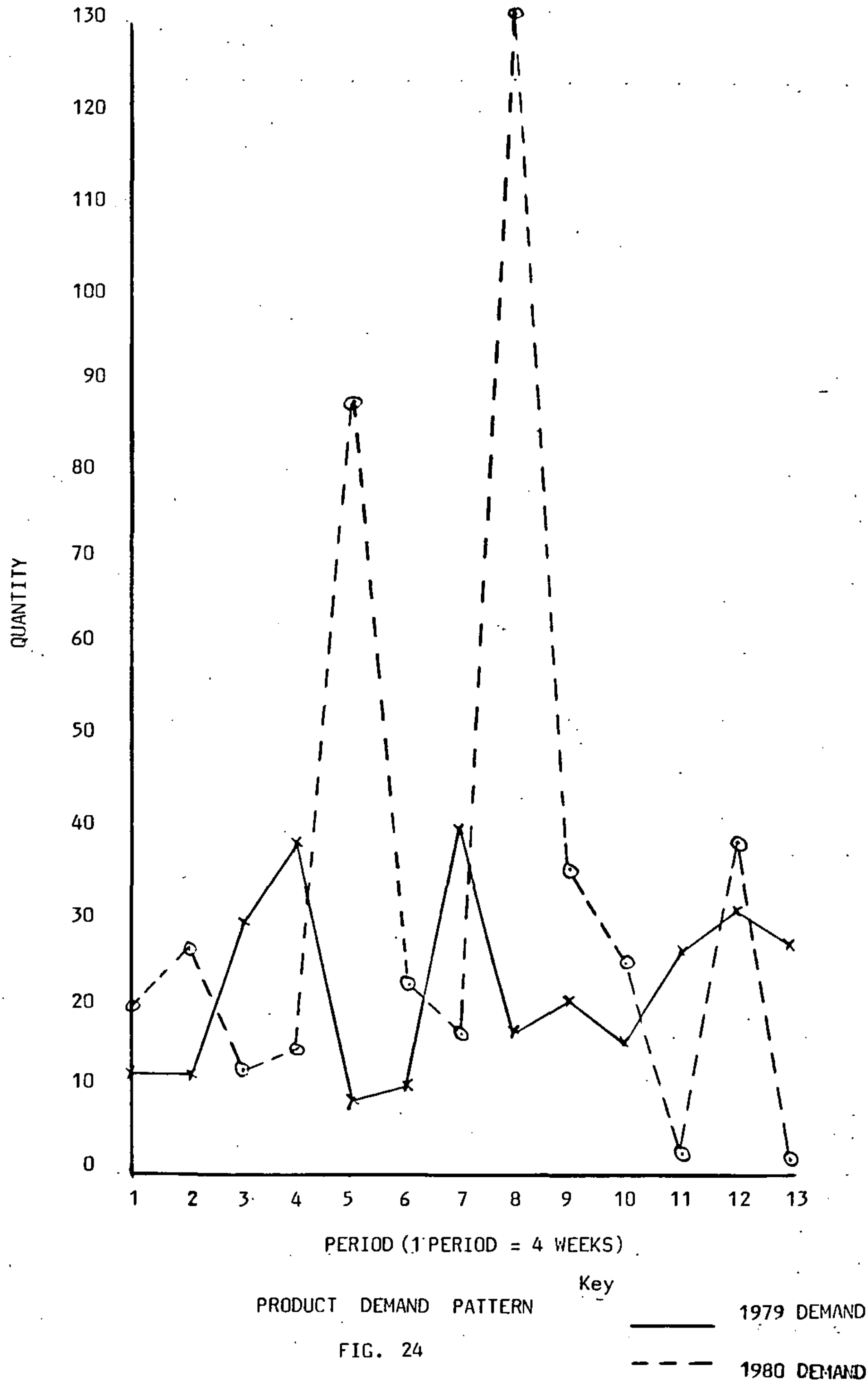
The investigation identified eleven items valued at £1 and over. The number of items issued and received at monthly intervals, together with the balance of stock at each month end, is presented over a one year period, i.e. 1980. (See Item 1 - 11 Apprendix A).

The actual demand for the product selected for investigation is shown in Figure 24. Although orders can be received at any time, the cumulative orders over four week periods are shown for 1979 and 1980. The quantities in each period represent the amount to be delivered to the customer in that period as distinct from the order receipt period.

It will be noticed that actual demands show apparent random peaks. These excessive demands have been investigated and several large orders from different sources contribute to the demand. The sources were further investigated to identify the cause which might help to predict such future occurrences. The conclusion was that the high irregular demands could not be associated with any known activity of a customer; consequently, such demands might occur at random intervals in the future.

Table 5 and Figure 25 offer further information about each item which will assist in the investigative procedure.

The lead times used in the research are average lead times derived from actual data. The cumulative lead time for the product in question is 83 weeks, but it is considered that the lead times observed will be inflated to some extent by the physical kitting arrangement, releasing orders to the shop floor before a full complement of items required are available, and releasing certain orders to the shop floor for quantities in excess of immediate requirements.



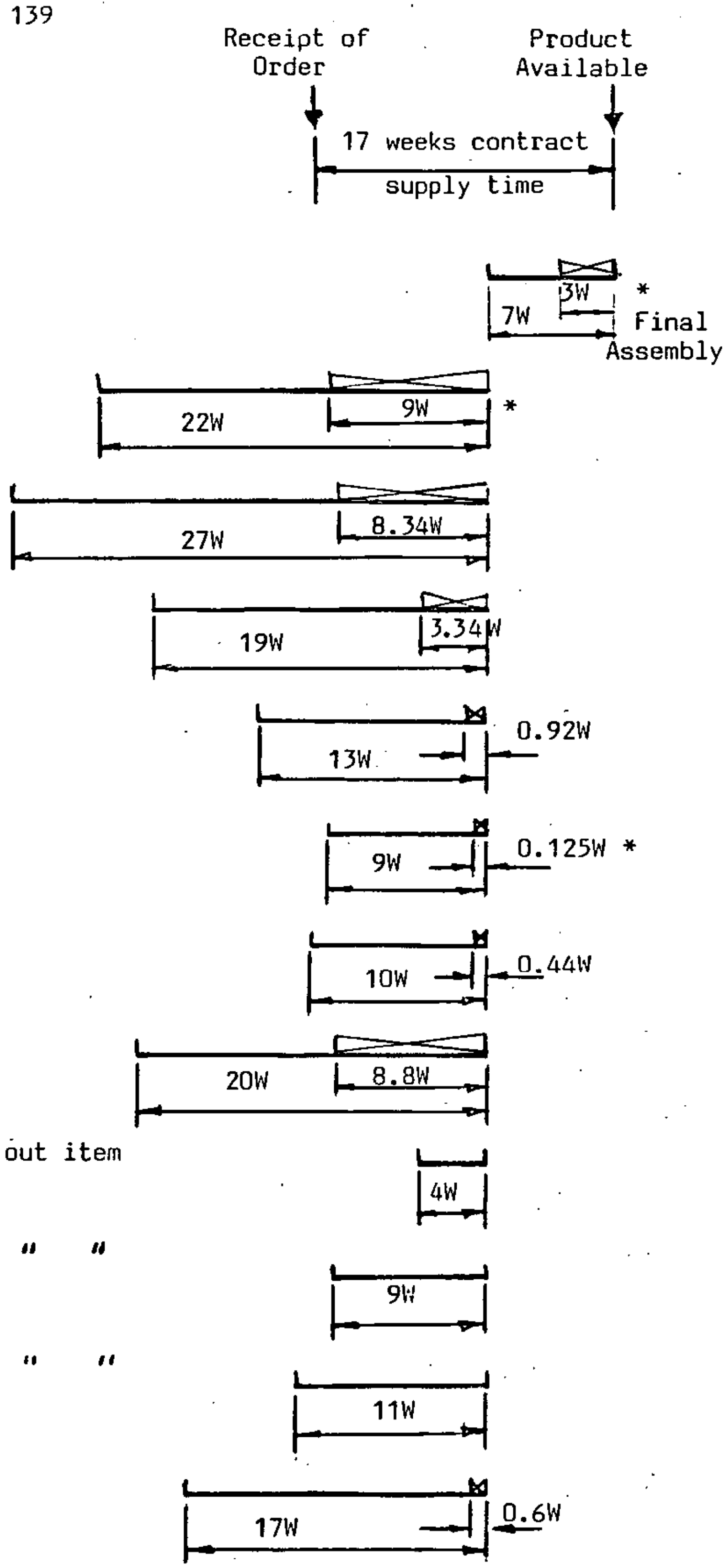
PRODUCT DEMAND PATTERN

FIG. 24

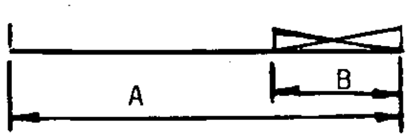
ITEM NO	COST £	ISSUED ALSO AS A SPARE	BOUGHT OUT	MADE IN	MANUFACTURING DEPARTMENT	PERCENTAGE DEPARTMENTAL OVERTIME WORKED IN ONE YEAR (1980)	NUMBER OF OUT OF STOCK CONDITIONS AT MONTH END DURING 1980
1	105	✓		✓	Assembly (1)	3.72%	12
2	56			✓	M/C Shop	20.38%	10
3	16			✓	M/c Shop	20.38%	9
4	9			✓	M/c Shop	20.38%	7
5	4	✓		✓	Assembly (2)	7%	2
6	4	✓		✓	Fabrication	13.77%	4
7	10			✓	Fabrication	13.77%	7
8	2		✓				1
9	2		✓				1
10	2	✓	✓				0
11	1	✓		✓	Fabrication	13.77%	5

TABLE 5

ITEM NO	LOT SIZE	
-	60	
1	60	
2	200	
3	200	
4	250	
5	200	
6	800	
7	500	
8	2000	Bought out item
9	500	" " "
10	1000	" " "
11	400	



KEY:



A = Historical Average Lead Time

B = Actual Work Content of Lead Time

* Assembly Time per person

RELATIONSHIP BETWEEN LOT SIZE, WORK CONTENT AND LEAD TIME

FIG. 25

CHAPTER X

BATCH SIZE DETERMINATION

10.1 Model Formulation and Application

It has been stated earlier that the master production schedule is the driving force behind the material requirements planning concept. It should be recognised that the master production schedule represents a plan for production and should not be confused with a forecast. Early in the investigation various dynamic and adaptive forecasting techniques were considered. These were abandoned after the cumulative lead time for the selected product was calculated; there would be little advantage in changing a forecast as a result of actual demand when certain raw materials required for the product have to be ordered 83 weeks before the product is made available to the customer.

It appeared reasonable to accept the product forecast presented by the Production Director and formulate a system which could adapt to any change in demand from the forecast. The Batch Size decision and batch scheduling approach can adversely affect the successful application of the master production schedule, making it necessary to consider in detail which batch size and scheduling technique will prove most suitable for the product in question.

The order point approach currently used by the company has the disadvantage of a low stock service level which is the result of multiple different items being required at the same time. Should a high aggregate stock service level be called for, it would mean excessive levels of stock being carried with a resultant high cost.

The following alternatives, identified earlier, may be applied to allow for the changes in demand from a set production schedule;

(i) adjusting the batch size;

(ii) keep the batch size constant and adjust the timing of the batch replenishment period;

(iii) a combination of batch size adjustment and replenishment timing.

After careful consideration of the literature surveyed on batch size decisions it was thought necessary to avoid nervousness of the system which could present severe problems when applying the dependent demand concept to lower level items in the product structure. The decision was therefore made to select a fixed batch quantity and manipulate the batch replacement frequency which assumes that the queue time component of the lead time may be controlled within the limits necessary to meet changing priorities.

The validity of this assumption rests on the very high proportion of queue time within a product lead time. and if necessary the possible use of additional resources such as overtime work, etc.

It was decided to avoid the theoretical models founded on economic criteria which are generally difficult to define with any degree of certainty. One approach which is not influenced by the limitation of stock holding cost and order/set-up cost was developed by Corke [19]. However, although the application showed a cost saving over the company's current batch size and ordering approach, it was limited by the fact that the resulting Batch Sizes varied for the eleven items investigated, thereby ignoring the dependent demand relationship in material requirements planning.

The "exchange curve" approach by Feeney [26] was excluded for the same reason as Corke's method, although the strategic decision on the amount of capital made available for stock has implications for high management and should be given serious consideration.

The model used in this reasearch has discounted the usual economic parameters but instead has tested different batch sizes and associated periods between batch replenishment to determine the degree of disruption of the master production schedule, resulting in the application of the two variables.

The model assumes a one hundred per cent customer service level; this is achieved by the manipulation of the batch replacement frequency. One of the major difficulties in the company investigated is the manufacture of the product in appropriate quantities to satisfy the volatile demand rate of the product in question. To allow for the volatile demand a constant batch size rule is applied. In addition a maximum stock level is set, the effect of which is to delay the scheduling of future batches as long as this level is exceeded. Once the stock level falls below the maximum level of stock, replenishment batches are again scheduled. Conversely, when the demand is higher than anticipated to the extent that stock levels will fall to zero, the batch schedules in progress will be brought forward to cover this.

This approach allows for the build of a variable but limited buffer stock when demand is low, to cushion the high demand rates, and it also offers a safeguard against excessive levels of stock being built.

10.2 Simulation of Demand

Elsewhere in the thesis is the recognition that a demand forecast for the product cannot be reliably produced. This presents a major barrier to the derivable and calculable dependent item quantities used in material requirements planning. It should be acknowledged that if a relieable forecast is available, the problems associated with material provisioning and scheduling are greatly reduced, and it might then be argued that the problems are non-existent.

The actual demand for the product could not be associated with a known frequency distribution, and consequently the probability distribution used in the model was empirically derived using the actual product demand over a two year period. From this the effects of different batch sizes on the resulting stock levels and schedule disruptions were assessed by a computer simulation. The stock levels were updated weekly.

It is suggested that if this model is employed by the company the two year actual product demand used for the probability distribution data in the simulation exercise would be updated yearly.

Figure 26 shows the frequency of actual demand quantities observed at weekly intervals during 1979 and 1980. From this information the following data was obtained :

Weekly demand quantity standard deviation	=	14.2757
mean value	=	6.8269
coefficient of variation	=	2.09

Maximum level of stock = batch size + buffer stock

Let buffer stock = $k\sigma_d \sqrt{R}$

where k = management service level factor (3 used in the model)

σ d = standard deviation of demand/week

R = duration in weeks between batch orders.

The management demand forecast was 360 units for one year and therefore the duration between batch orders commensurate with a batch size of

$$21 \text{ units} = \frac{52}{360 \div 21} \simeq 3 \text{ weeks} = R$$

Hence for a batch size of 21 units with a 3 week re-order cycle, the buffer stock will be :-

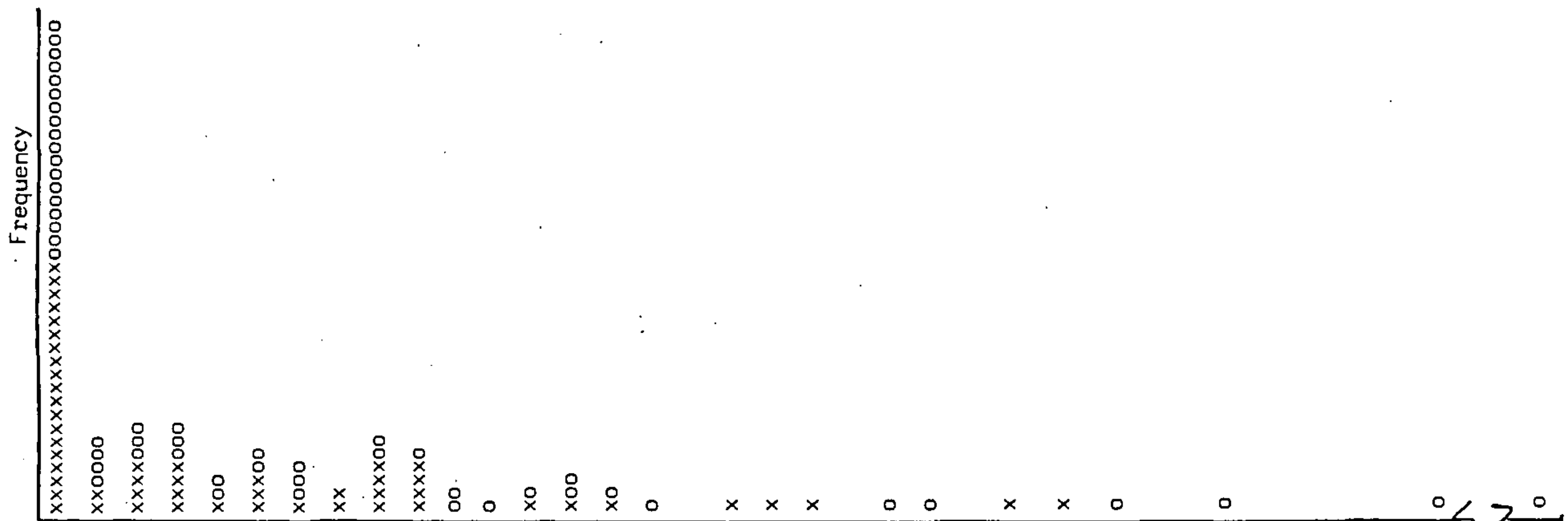
$$3 \times 14.2757 \sqrt{3} \simeq 74 \text{ units}$$

$\therefore$ Maximum stock level = 21 + 74 = 95 units

KEY:

x 1979

o 1980



Quantity	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	132
Frequency	37	6	7	7	3	5	4	2	6	5	2	1	2	3	2	1	-	1	1	1	-	1	1	-	1	1	1	-	1	-	-	-	1	1
Cumulative Frequency	37	43	50	57	60	65	69	71	77	82	84	85	87	90	92	93	93	94	95	96	96	97	98	98	99	100	101	101	102	102	102	102	103	104

FIG. 26 QUANTITY DEMANDED IN WEEKLY PERIODS

The time between batch replenishment periods commenced with a one week duration and was progressively increased by weekly amounts to a maximum of twenty four weeks. Table 6 shows the batch sizes, replenishments interval, buffer stock and maximum stock levels appropriate to a forecast of 360 units supplied during a one year period.

Batch Size (Units)	Duration Between Batches (weeks)	Buffer Stock	Maximum Stock Level
7	1	43	50
14	2	61	75
21	3	74	95
28	4	86	114
35	5	96	131
42	6	105	147
48	7	113	161
55	8	121	176
62	9	128	190
69	10	135	204
76	11	142	218
83	12	148	231
90	13	154	244
97	14	160	257
104	15	166	270
111	16	171	282
118	17	177	295
125	18	182	307
132	19	187	319
138	20	192	330
145	21	196	341
152	22	201	353
159	23	205	364
166	24	209	375

TABLE 6

10.3 Application of Model

To overcome the instability of the results caused by the inertia of the initial periods of supply and demand, and to allow for the maximum level of stock to be achieved and to demonstrate its effect on the results, a 100 year period was used for each batch size tested, each period being repeated six times.

The iterations were carried out on a Systime 6000 computer. A flow chart showing the programme logic and data processing operations is shown in Fig. 27.

When the stock level reached a negative value the next batch supply is brought forward to satisfy the demand; the resulting number of weeks which the batch supply is moved, is calculated and shown as the 'number of weeks of disruption'. Once a batch supply period is changed the periods between subsequent batch replenishments are also brought forward by the same amount, thus keeping the time periods constant. (see Fig. 28).

When the maximum stock level is exceeded the following batch replenishments are delayed until the stock level falls below the maximum stock level allowed (see Fig. 29). Disruptions created by this rule are considered not to cause undue concern to the manufacturing facility and providing they occur infrequently, such disruptions may be ignored. However, should the cancellation of future batch replenishments occur frequently, this will be a sign that the mean demand forecast used in the master production schedule is overestimated and steps may be taken to review the batch size or planned period between batch replenishment, or both, in an attempt to stabilise the system. Conversely, should the forecast be underestimated

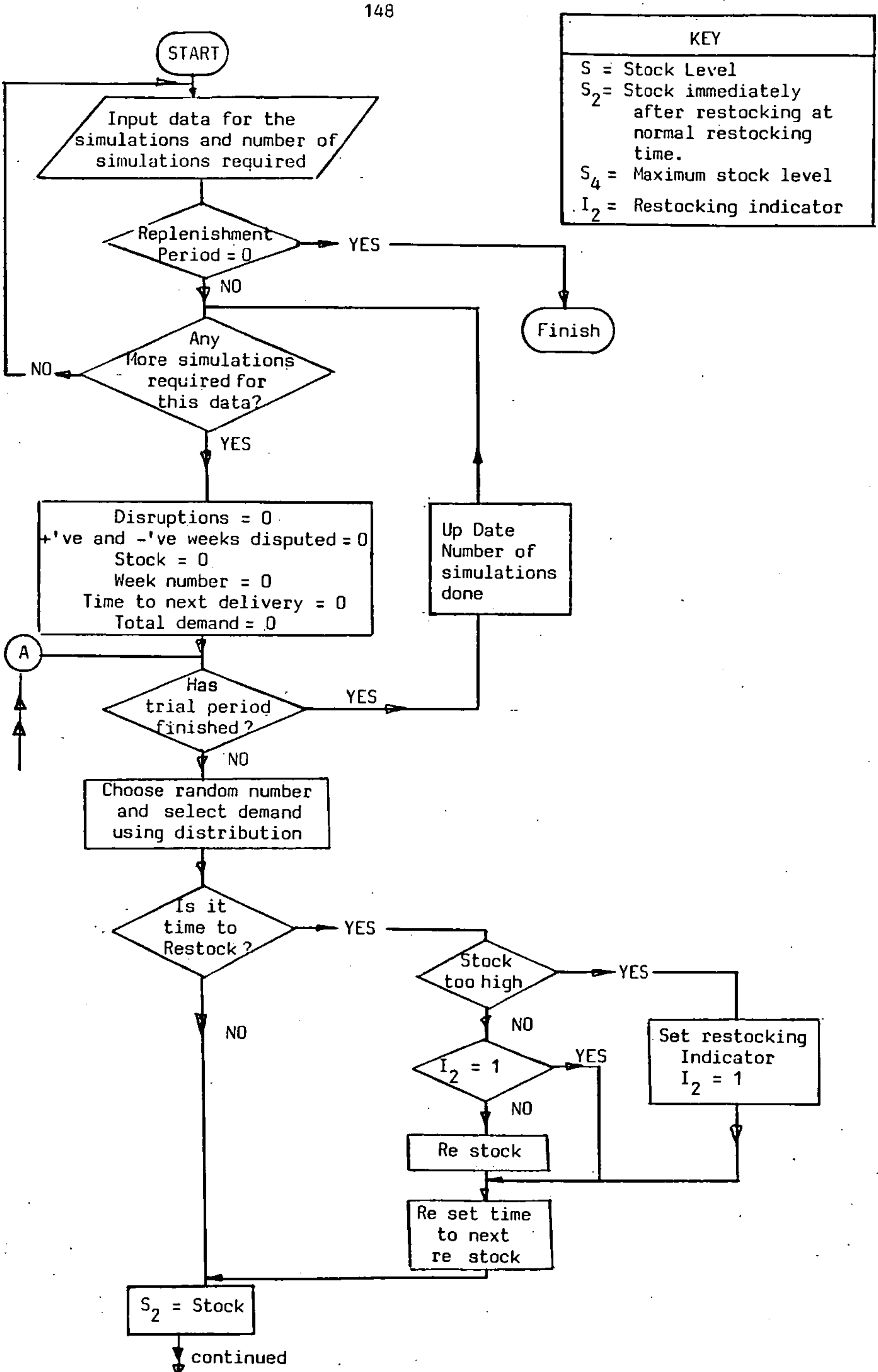
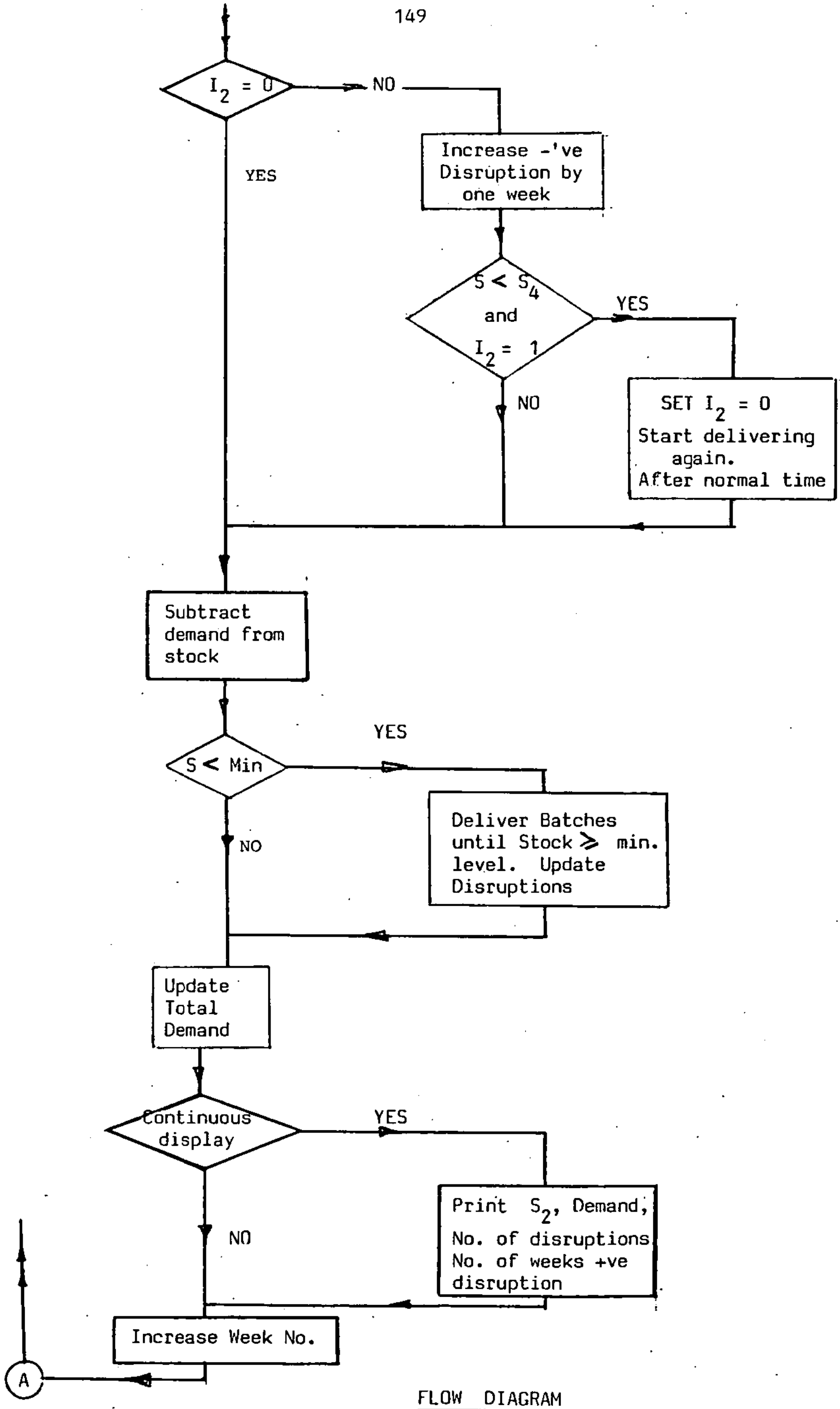
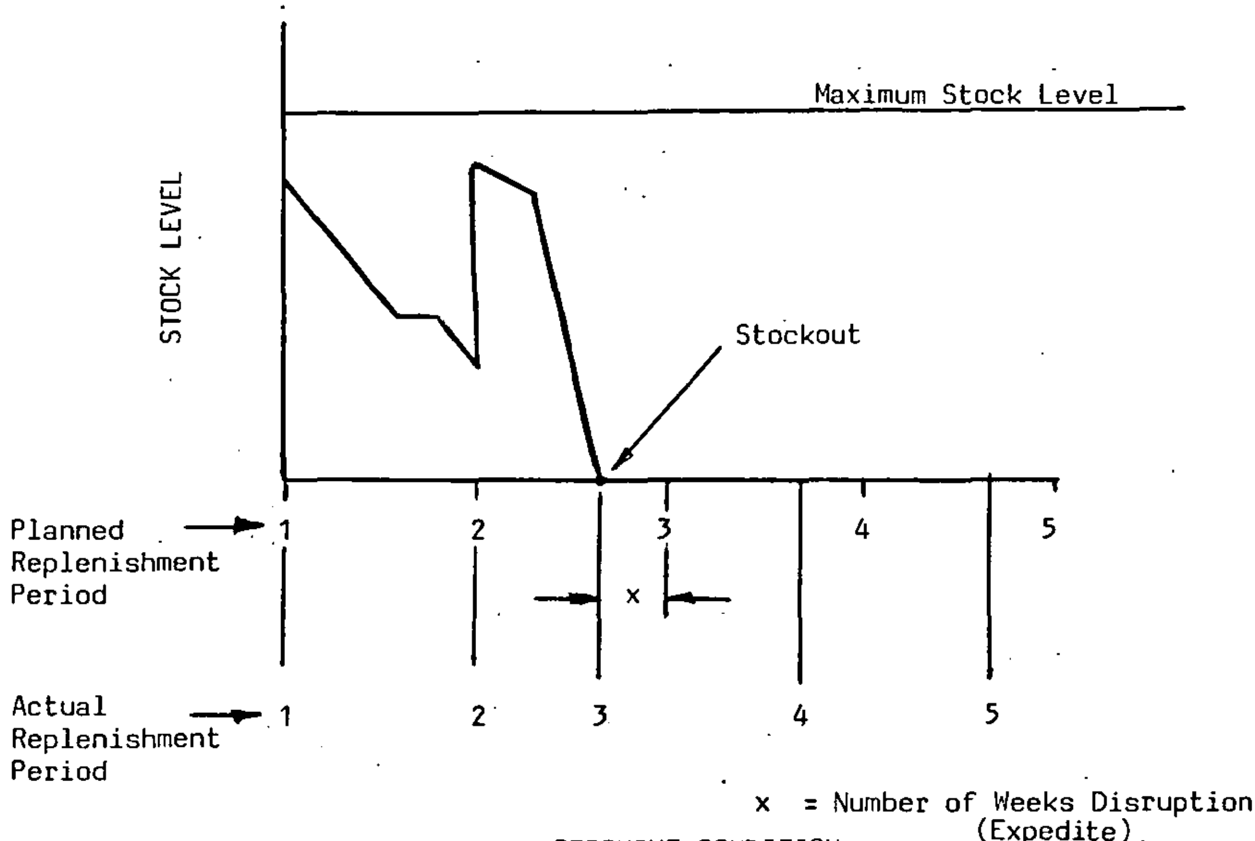

KEY
S = Stock Level
S2= Stock immediately after restocking at normal restocking time.
S4 = Maximum stock level
I2 = Restocking indicator
START
Input data for the simulations and number of simulations required
Replenishment Period = 0
YES
Finish
NO
Any More simulations required for this data?
NO
YES
Disruptions = 0
+'ve and -'ve weeks disputed = 0
Stock = 0
Week number = 0
Time to next delivery = 0
Total demand = 0
Up Date Number of simulations done
A
Has trial period finished?
YES
NO
Choose random number and select demand using distribution
Is it time to Restock?
YES
Stock too high
YES
NO
Set restocking Indicator I2 = 1
NO
I2 = 1
YES
NO
Re stock
Re set time to next re stock
S2 = Stock
continued

FIG.27



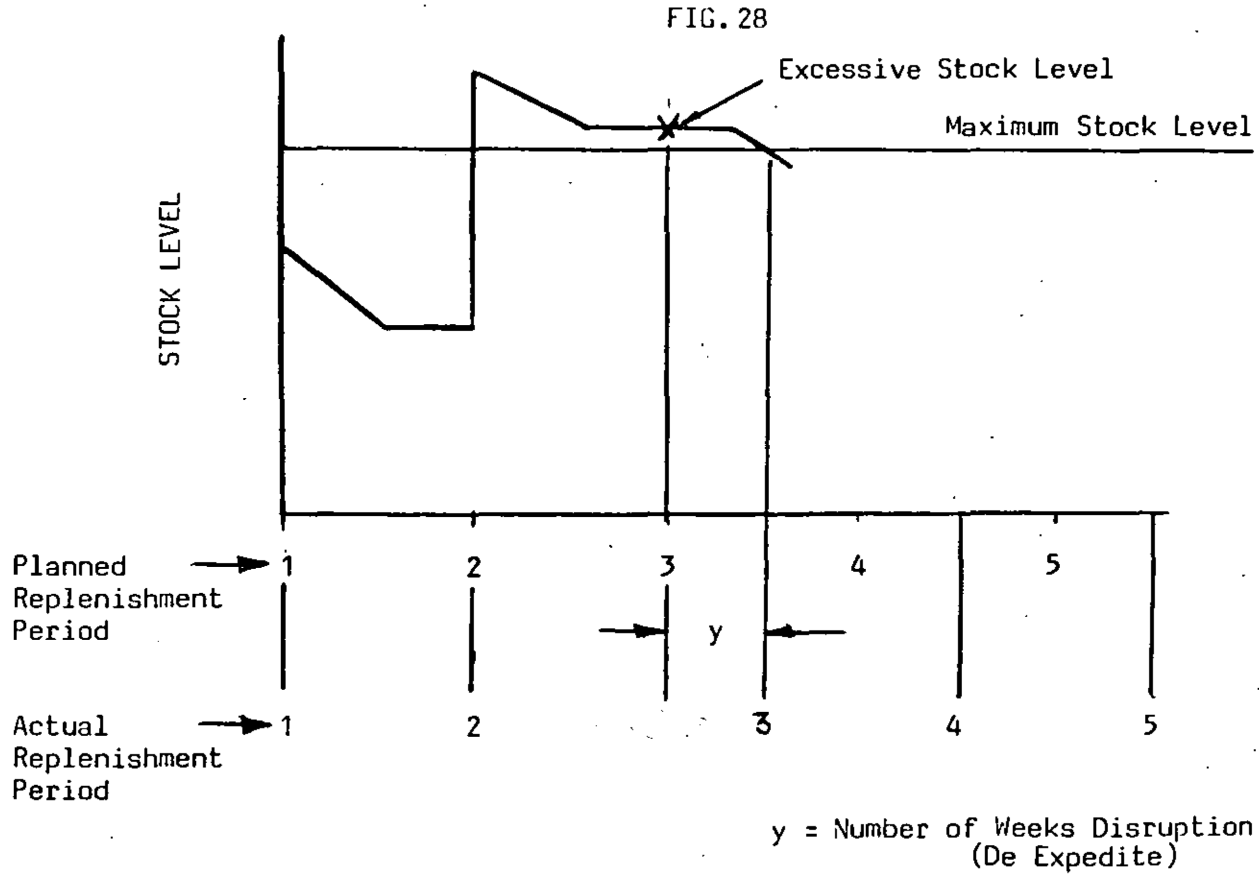
FLOW DIAGRAM

FIG. 27 (cont'd)



STOCKOUT CONDITION

FIG. 28



EXCESSIVE STOCK CONDITION

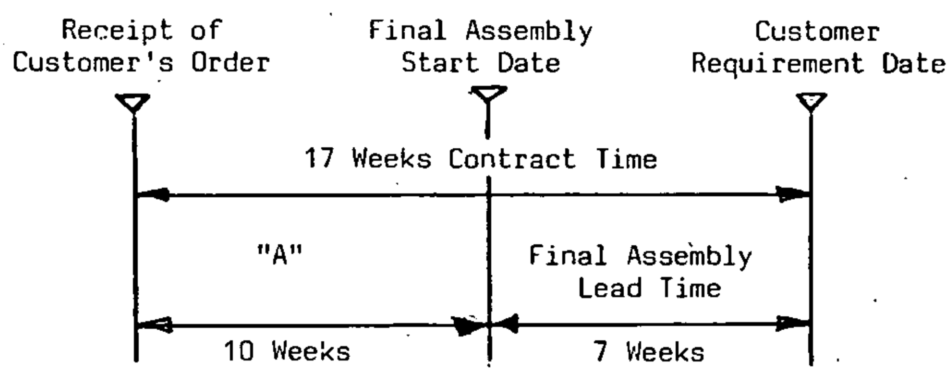
FIG. 29

resulting in excessive weekly disruptions which cannot be stabilised by the maximum level of stock ,again this will indicate a review of the batch size or planned period between batch replenishment, or both.

Figure 30 shows the results obtained from the model with each dependent variable representing the mean value of the six trials taken. Dividing the weekly disruption (disruptions to schedule caused by shortages only) by one hundred gives the average yearly disruptions expected with the batch size and the associated replenishment period tested.

10.4 Analysis of Component Lead Times

The final assembly lead time and the contract time agreed between the customer's order placement and product delivery date will determine the amount of time in which any changes in the master production schedule can be considered. Figure 31 shows the current 'planned' lead times.



MANUFACTURING AND CUSTOMER LEAD TIMES

FIG. 31

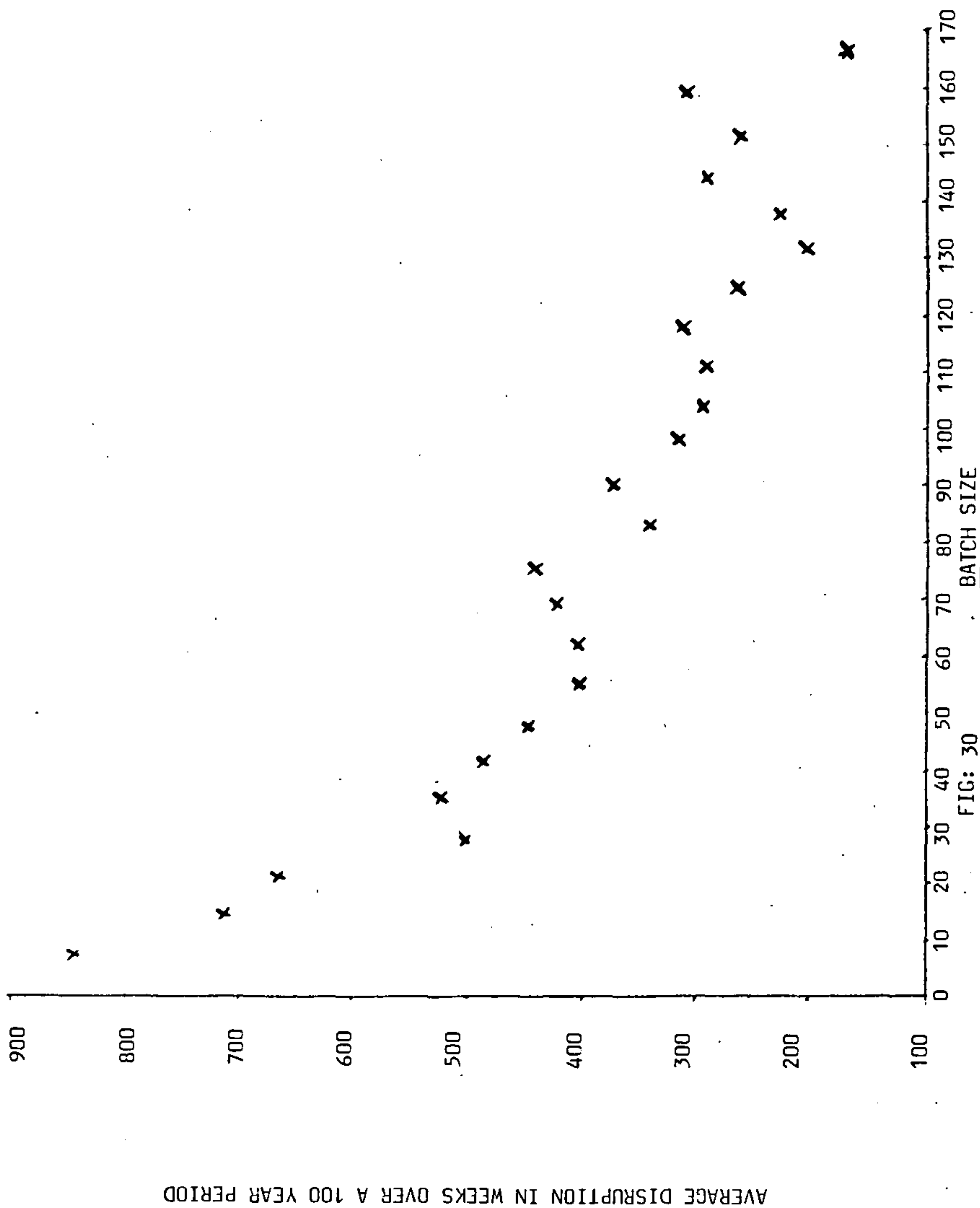

BATCH SIZE
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170
AVERAGE DISRUPTION IN WEEKS OVER A 100 YEAR PERIOD
100 200 300 400 500 600 700 800 900

FIG: 30

Period 'A' will depend on the contract agreement between the manufacturer and customer. With the current contract agreement of 17 weeks, a 10 weeks notice is given of the actual requirements prior to commencing the final assembly operation. This period will allow the master production schedule to be expedited or de-expedited to meet changing demand. When a signal to expedite is given, the action may require the shortening of planned lead times in lower levels of production unless a decision has been made to hold excess levels of stock in these areas.

The eleven 'level 2' items previously identified as the 'major' requirements in the final assembly have been analysed separately to assess each item's capability of responding to a 'make in less than planned lead time' request. The analysis gave the following results:

ITEM	Cost/each	Planned Lead Time	Actual Work Time
No.1	£ 105	22 weeks/batch of 60	9 weeks/batch of 60/person

Other Considerations:

Assembly operation - the planned lead time and work time depend upon the number of people employed on the assembly of the item. There should be no barriers to reducing the times considered. This item is also issued as a spare, and hence additional quantities will be manufactured to meet the forecast of demand for spares.

ITEM	Cost/each	Planned Lead Time	Actual Work Time
No.2	£ 56	27 weeks/batch of 200	8.34 weeks/batch

Other Considerations:

This item is manufactured in the machine shop, which has a history of overtime working. Three machines are available which are capable of manufacturing this item although only one fixture is available. The times given may be reduced.

ITEM	Cost/each	Planned Lead Time	Actual Work Time
No.3	£ 16	19 weeks/batch of 200	3.34 weeks/batch

Other Considerations:

These items are machined castings; the raw casting is ordered from an outside supplier in quantities of 200. The castings are not used elsewhere. Castings may be received which prove unsuitable due to blowholes which are only evident on machining. It is recommended that all castings are machined as soon as possible after they are received at the company so that additional castings can be supplied to replace the faulty ones. The relatively low cost of these items and quality difficulties suggest a two bin system of stock control. Consquently, expediting should cause no problem.

ITEM	Cost/each	Planned Lead Time	Actual Work Time
No.4	£ 9	13 weeks/batch of 250	0.92 weeks/batch

Other Considerations:

These are machined castings and therefore the same reasoning as Item No. 3 can be applied, i.e. use a two bin system.

ITEM	Cost/each	Planned Lead Time	Actual Work Time
No.5	£ 4	9 weeks/batch of 200	0.125 weeks/batch

Other Considerations:

Assembly operation. Issued also as a spare. Treat as Item No. 1.

ITEM	Cost/each	Planned Lead Time	Actual Work Time
No.6	£ 4	10 weeks/batch of 800	0.44 weeks/batch

Other Considerations:

Only one machine available for each operation to be performed. The large batch size and extended queue time suggests the 10 week lead time is inflated.

ITEM	Cost/each	Planned Lead Time	Actual Work Time
No.7	£10	20 weeks/batch of 500	8.8 weeks/batch of 500

Other Considerations:

The two longest operations could be performed on other machines to reduce work time. The large batch size could be reduced if required.

ITEM	Cost/each	Planned Lead Time	-
No.8	£ 2	4 weeks/batch of 2000	

Other Considerations:

Bought out item. Difficult to reduce lead time. Should not present a shortage problem when bought in batches of 2000.

ITEM	Cost/each	Planned Lead Time	-
No.9	£ 2	9 weeks/batch of 500	

Other Considerations:

Bought out item - apply same reasoning as Item No.8.

ITEM	Cost/each	Planned Lead Time	-
No.10	£ 2	11 weeks/batch of 1000	

Other Considerations:

Bought out item - apply same reasoning as Item No.8.

ITEM	Cost/each	Planned Lead Time	Actual Work Time
No.11	£ 1	17 weeks/batch of 400	0.6 weeks/batch

Other Considerations:

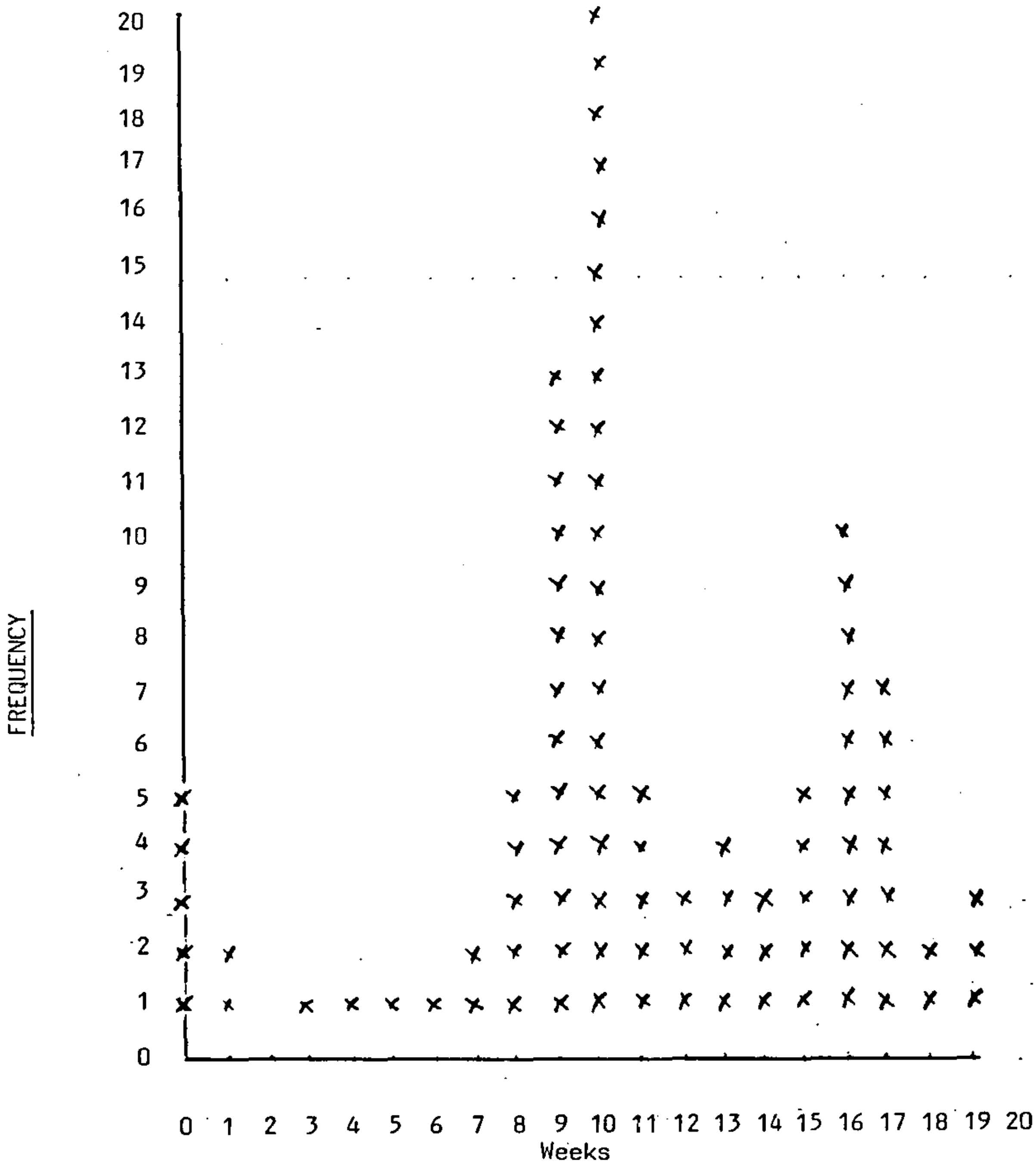
The longest operation on this item can be performed on another machine which will reduce the lead time. The large batch size and extended queue time suggests that the 17 week lead time is inflated. Issued also as a spare.

The analysis indicates that the reduction of lead time is feasible for all manufacturing and assembly items. Items from outside are currently supplied in large quantities which should not present shortage difficulties when additional demand is made.

Although the contract delivery lead time agreed between the customer and the manufacturer for the supply of goods was stated to be 17 weeks during 1980, Fig. 32 shows the actual lead time requested by the customer during the period. The arithmetic mean lead time requested is 10.83 weeks.

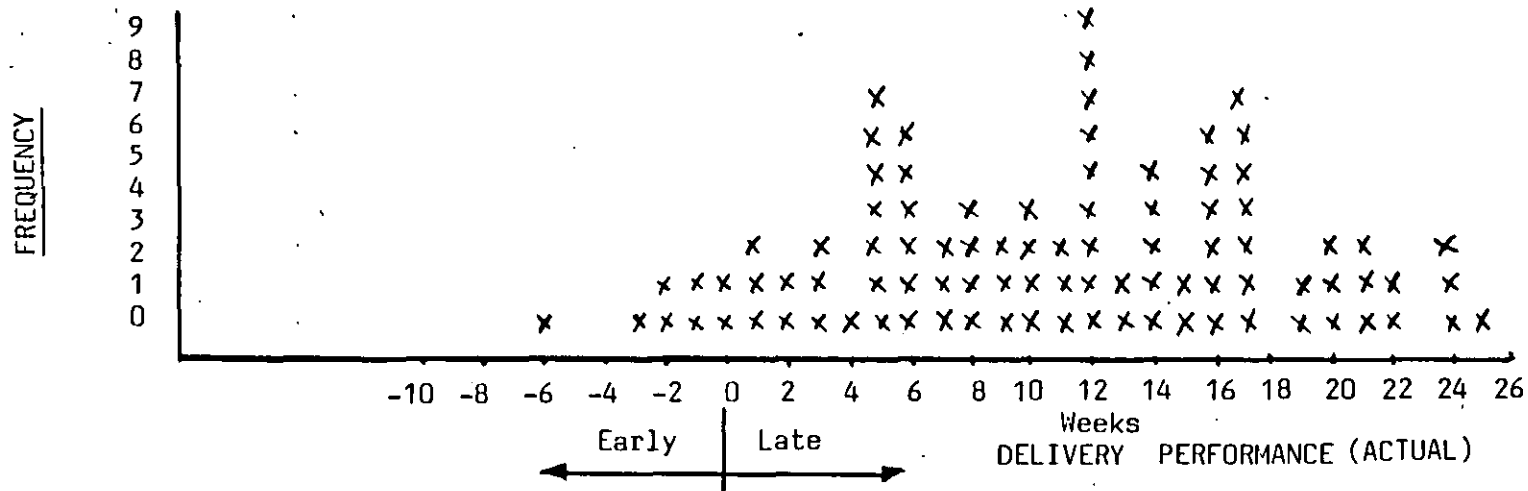
The actual delivery performance during 1980 is shown in Fig. 33. An order is considered complete when the quantity required is made available to the customer; this ignores any part fulfilment of an order which may occur.

Fig. 34 shows, for the 1980 orders investigated, how an improved delivery performance could have been achieved by the manufacturer if the contract lead time had been honoured by the customer.



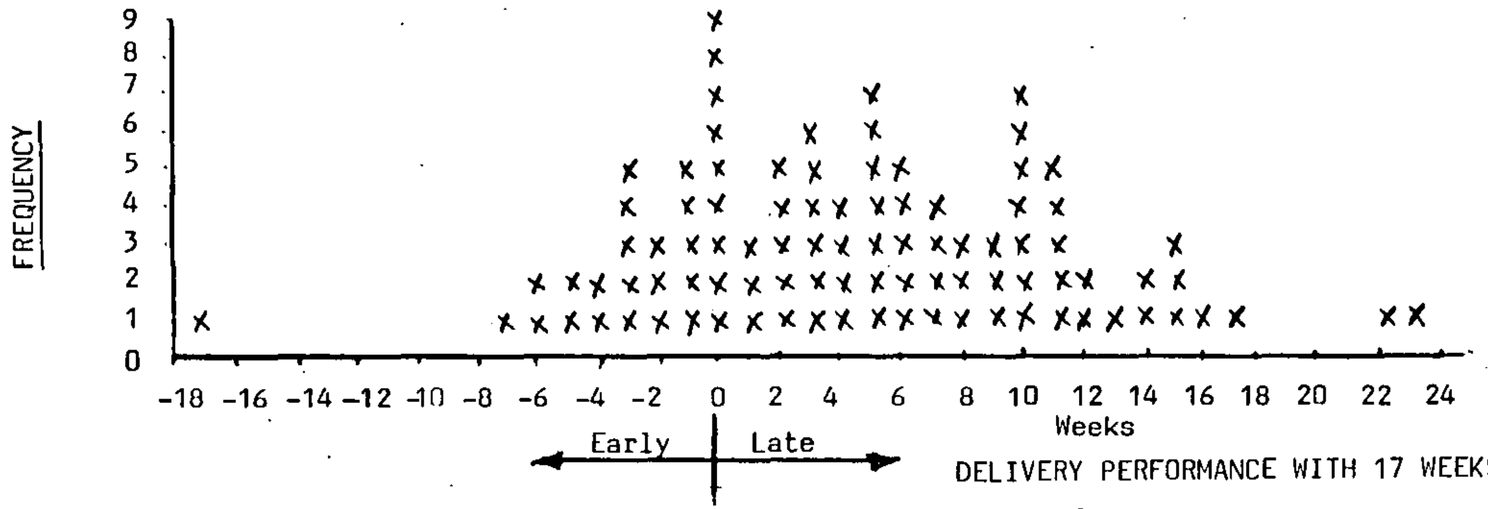
ACTUAL LEAD TIME GIVEN BY CUSTOMER
FROM DELIVERY CONTROL COPY

FIG: 32



DELIVERY PERFORMANCE (ACTUAL)

FIG: 33



DELIVERY PERFORMANCE WITH 17 WEEKS LEAD TIME

FIG: 34

CHAPTER XI

SUMMARY AND CONCLUSIONS

It is necessary, to achieve the objective of this study, to recognise how effective the applied production planning and control theory is within the company investigated, and also to determine if the current effectiveness of the production control department can be improved by the application of additional or alternative theories.

The effectiveness of production planning and control may be measured in a number of ways depending upon which particular body is effected by the outcome. To allow a rational judgement to be made on the overall effectiveness of the current production planning and control system within the company investigated, it is suggested that the system is measured by the delivery performance of goods to the customers. Perhaps in any situation the delivery of products on time, at the correct quality and in the correct quantity should be a prime objective of a company. However, one must recognise that the strategic decisions made by higher management on the availability of resources and finance will have a profound effect on the tactical decisions made by lower management who have to implement the company policy to achieve some set objective.

One basic decision which needs to be made at the inception of a production control system is the 'product positioning' policy, i.e. where stock levels are to be held.

It is considered that the company concerned should adopt an 'intermediate position' for the product investigated, which requires the anticipation of customers' orders by forecasting future demand

and holding stocks of raw materials and semi-finished products. It has been mentioned earlier that the product can be supplied in alternative final arrangements to suit the particular need of the customer; to keep these alternatives in stock would commit excessive capital in finished goods stock. The intermediate product positioning policy results in a quicker response to orders than a pure make to order policy.

The decision to stock semi-finished goods is particularly advantageous when these goods are also offered as spares. It can be claimed that products and the associated spares have an 'extended' life cycle in this type of industry. This is due to the special needs of the customer where the safe operation and worker confidence in the product are of paramount importance. Products which are used in highly inflammable atmospheres are awarded a certificate of conformance only after rigorous and extensive tests have been carried out. Design or material changes to existing products necessitate the re-testing and certification of the product. These stringent conditions, however, offer some advantages to the manufacturer. Once a product has been accepted and installed by the customer, the decision to change allegiance to another manufacturer is a difficult one to make, particularly when, for example, a coal mine is equipped with a complete system manufactured by one company and competitors products are not compatible. Obviously, this will also guarantee the orders for the supply of spare parts to the company who installed the system. Obsolesence of any product would be known well in advance if the producing company is aware or involved in the manufacture and testing of replacement products.

This type of customer commitment to a manufacturer can have serious repercussions, particularly when the manufacturer has a poor customer service record for spare parts. The customer will have little choice but to wait for his needs to be satisfied; however, when the time comes to install a new system there is the likelihood that the customer will change the supplier. In the instance of the National Coal Board, an order for a complete system and associated spares will represent a vast amount of money. The scale of future orders is a factor which the supplier should bear strongly in mind when he makes decisions on the service levels for his customers.

The following observations may be made from studying stock control record cards and associated graphs (Appendix 'A'). The company generally does not hold sub-assemblies in stock. The immediate usage of parts upon their receipt in stores suggests that production is delayed until the parts are available. Table 5 indicates that overtime is being worked due to custom, not necessarily job priority. For example, assembly department 1 has the highest 'out-of-stock' record yet over the period documented only 3.72% of overtime was worked. This is mainly due to the labour resources available in the assembly department which is predominantly female. The experience of the company is that this category of labour resists overtime working. Additional output in the area would not necessarily commit the company to excessive expenditure on equipment if it is thought desirable to maintain female workers (renowned for their dexterity on fine assembly work). A 'twilight' shift might be considered to reduce a constant overload in the department.

The delivery performance of the product investigated indicates that the production planning and control function within the company is not as effective as it might be. It is acknowledged that the production control problem is compounded with the inherent volatile product demand and long lead times. Although the volatile demand is not under the control of the company's production department, it is suggested that the long lead times observed could be substantially reduced by production control action. The relationship between lead time and work time indicates excessive queue times for most items; this could be caused by one, or by a combination of, the following conditions:

(a) Orders are released to the shop floor irrespective of the availability of resources, i.e. men, materials or machines.

(b) Orders are released to the shop floor well in advance of need.

(c) Large batch sizes are requested on the order but parts are supplied in smaller batches, either to meet an immediate need or limited by the availability of resources. This can result in the completed order date not revealing a progressive fulfilment of the order.

Although the company have a computerised production control system there is little evidence of any proper control of the manufacturing resources. In fact the evidence suggests an abdication of any thorough planning and control, with the system merely reacting to immediate needs. However, it is considered that the production planning and control problem can be minimised and the customer service improved if the company apply the theory developed in this research.

Because of the shortfalls of the statistical inventory control theory, particularly when it is applied to large quantities of parts needed to manufacture a product similar to the one investigated, and the 'lumpy' demand for lower level parts associated with manufacturing in batch quantities, it is recommended that the company adopt the material requirements planning concept for all its manufactured products.

For the particular product investigated, the yearly forecast supplied by the Production Director should be used for the independent demand and the dependent demand quantities of lower level sub-assemblies and parts can be calculated from the product forecast. Additional quantities of sub-assemblies and parts which are also issued as spares will be added to the dependent demand quantity after an independent forecast for spares has been made.

The previous observation on product positioning should be more specific and therefore it is recommended that the eleven sub-assemblies and parts (at level 2) are held in stock thereby enabling the company to meet the customers volatile requirements whilst maintaining a relatively stable production environment.

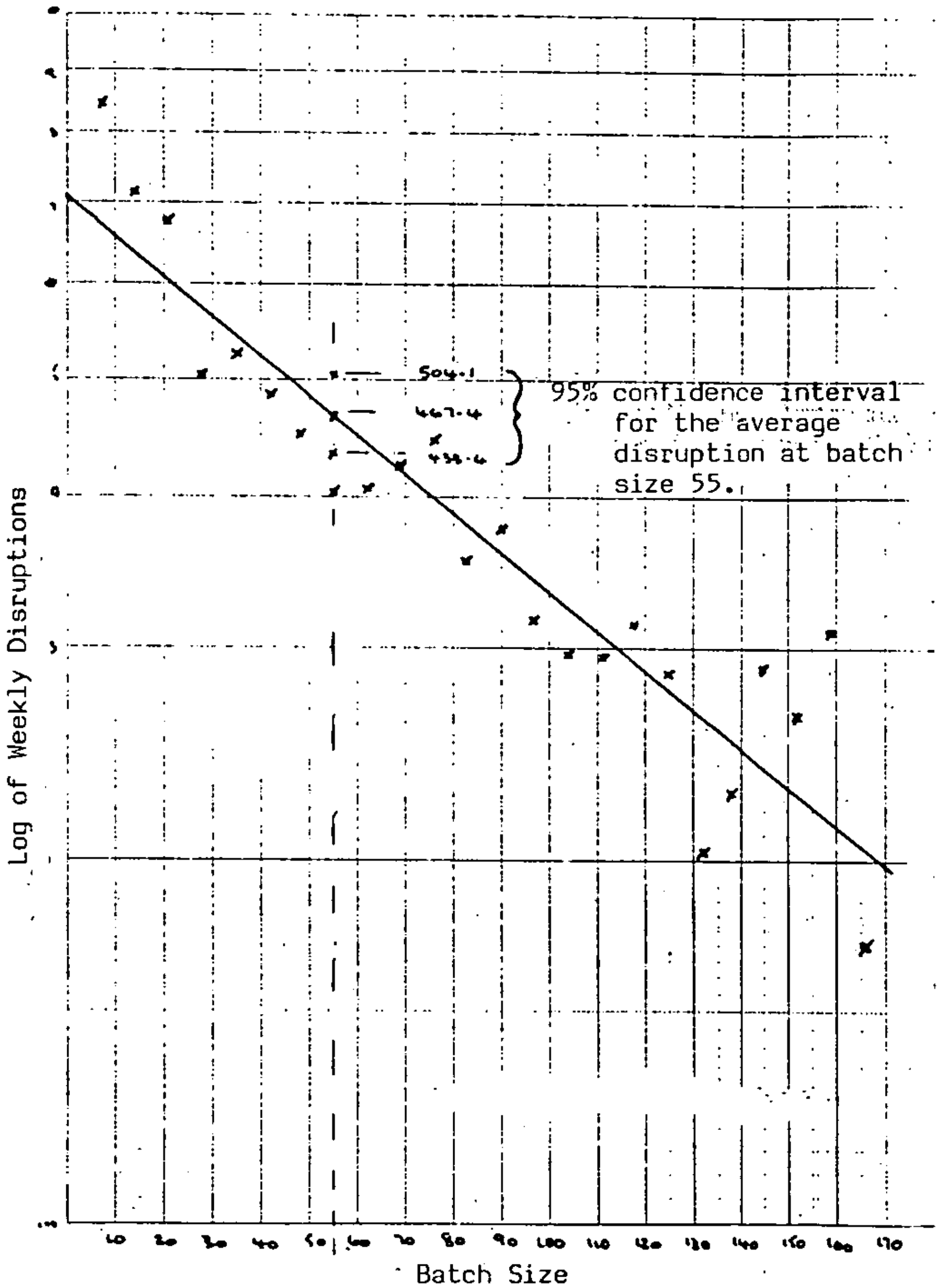
The stock holding model developed attempts to minimise the disruptive effects on the company's manufacturing facilities caused by the volatile demand and long lead times. The model employs the time phased order point approach and develops a constant batch size for use in the master production schedule to overcome lower level component nervousness. Any excessive variation in the actual demand compared to the forecast demand may be accommodated by adjusting the batch replenishment period.

The system reaction to demand change is dampened by the application of a maximum stock level. This allows for the build up of stock to the maximum stock level, whereupon future planned replenishment batches are suspended until the stock level drops below the maximum level.

Due to the difficulty in forecasting future requirements, disruptions in the production schedule are inevitable. The degree of disruption is a corollary of the batch size employed. The amount of disruption to the production schedule increased with the decrease in batch size. However, this does not necessarily imply that large batch sizes should be encouraged. On the contrary, one objective is to reduce batch sizes until a tolerable disruption level is achieved. The rationale of reducing batch sizes is to limit the amount of work in process and increase the flexibility of the manufacturing facility.

For the product investigated, a batch size of 55 is recommended with an eight week replenishement cycle, allowing a maximum stock level of 176. This is a fictitious level of stock for the product, the figure being used to make available sufficient level 2 components and sub-assemblies to build 176 products for the time when an order is received from a customer identifying the product final arrangment. The batch size chosen will result in an average of four weeks disruption per year. The analysis of the major components and sub-assemblies shows that it is feasible to accommodate this amount of disruption.

An analysis was carried out of the linear regression of the logarithm of the average weekly disruptions on the batch size, using data arising from the simulation exercise. A good fit was obtained (see Fig. 35) with a correlation coefficient of 0.9285, indicating that



LOGARITHM OF WEEKLY DISRUPTIONS V. BATCH SIZE

FIG. 35

the number of disruptions (N) and the batch size (D) are related by the expression:

$$D = Ae^{BN}$$

where A and B are constants.

Values for A and B were calculated using the method of least squares, indicating that D and N are related through:

$$D = 7.1e^{-0.0075N}$$

Should batch sizes of 30 and 80 be chosen, the number of weeks disruption to the master production schedule would be approximately 5½ weeks and 3½ weeks respectively. The curve (Fig. 30) indicates that the weekly disruptions do not have a linear relationship with the batch size and the principle of 'diminishing return' is appropriate with the increase in batch size. There is another consideration when associating batch sizes and disruption; will a one week, say, disruption with a small batch size be as significant as a one week disruption with a large batch size when changing a schedule? Probably the manipulation of a smaller batch size will create less difficulties to a shop load than will the manipulation of a larger batch size. This observation may possibly be related to the scheduling literature previously reviewed where the shortest processing time priority rule generally exhibits the best shop performance when compared with other scheduling rules.

One must consider additional factors as well as the affect of changing the batch size to minimise the disruption to a master production schedule caused by fluctuating demand.

It is also necessary to ensure that:

1. The machines and equipment used in the manufacturing process are well maintained and that additional excessive disruptions are not caused by plant breakdown.

2. The labour force is aware of what the production department is trying to achieve and it is fully trained to effectively use the plant and equipment at its disposal.

3. Disruptions are not caused by lateness and absenteeism due to low morale.

4. Correct working methods are selected, installed and continuously monitored and up-dated.

5. Set-up time between batch changeover are at a minimum with the application of fixtures and standby equipment where necessary.

6. The correct and well maintained tools are readily available to assist in the continuity of the manufacturing process.

The above points are not exclusive. It is necessary for management to fully back any action necessary to promote any of the above requirements without which the use of computers and improved production control techniques will prove merely cosmetic resulting in little, if any, improvement in the manufacturing of goods to meet the requirements of the customer.

It should also be recognised that if there is any substantial increase in demand for products on the master production schedule, it will be necessary to re-think the strategy if the demand is to be satisfied. The new strategy could include:

(i) sub-contracting work.
(ii) additional shifts.
(iii) additional resources.

Should the company choose to adopt material requirements planning, it will be necessary for the following areas to be fully scrutinised by management. These areas are the pre-requisities for the successful application of M.R.P.

(i) A master production schedule; an effective master production schedule can be produced if the procedure used during this research is followed for all products or provisionally all category 'A' products.

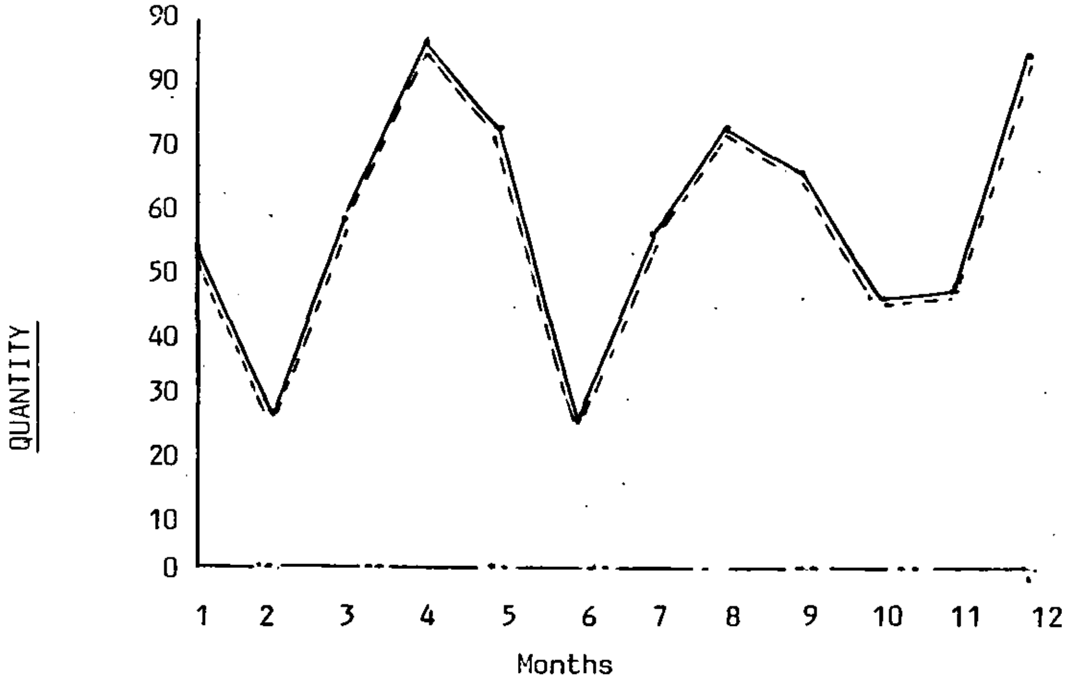
(ii) A bill of material and bill of material structure; the company have these available for a limited number of products. The authenticity of some earlier bills of material and structures was in doubt due to changes made by unauthorised personnel. It is of paramount importance that a well documented procedure is followed whereby any modification to a bill of material or structure can be carried out at one source only and such changes fully communicated throughout the organisation, with the appropriate erasure of previous data.

(iii) Valid, up-to-date inventory records; it is necessary for the company to overhaul the method of recording stock movement on the computer file. It is not uncommon for dual systems to operate during the introduction of a new technique but when the computer file is generally ignored and preference given to the manual card system with no attempt to phase out the manual system, confidence in computer read-outs will never be achieved.

M.R.P. can only be effective when the dependent demand relationship between components and products can be exploited. The extended lead times identified in this study and the volatile demand make the quantities of lower level requirements calculated from the master production schedule, questionable.

The writer cannot accept the inference that M.R.P. will work effectively with a master production schedule produced by a bad forecast [49]. Long lead times in excess of the customer requirement lead time, when associated with a random, highly variable demand, will need safety stocks of lower level components if the customer requirements are to be met. Otherwise the long lead times will not allow sufficient time for the provision of components. However, should the batch and batch replenishment technique developed during the research be adopted, the resulting stable production programme showing minimal disruption from the planned programme will enable material requirements planning and capacity requirments planning to be successfully applied particularly when safety stocks are held on critical lead time components.

Probably material requirements planning will act as the catalyst needed to co-ordinate the activities of the separate parts of the organisation. It may promote a dialogue between these parts and facilitate the customer service objective to be achieved with the optimum use of the resources available.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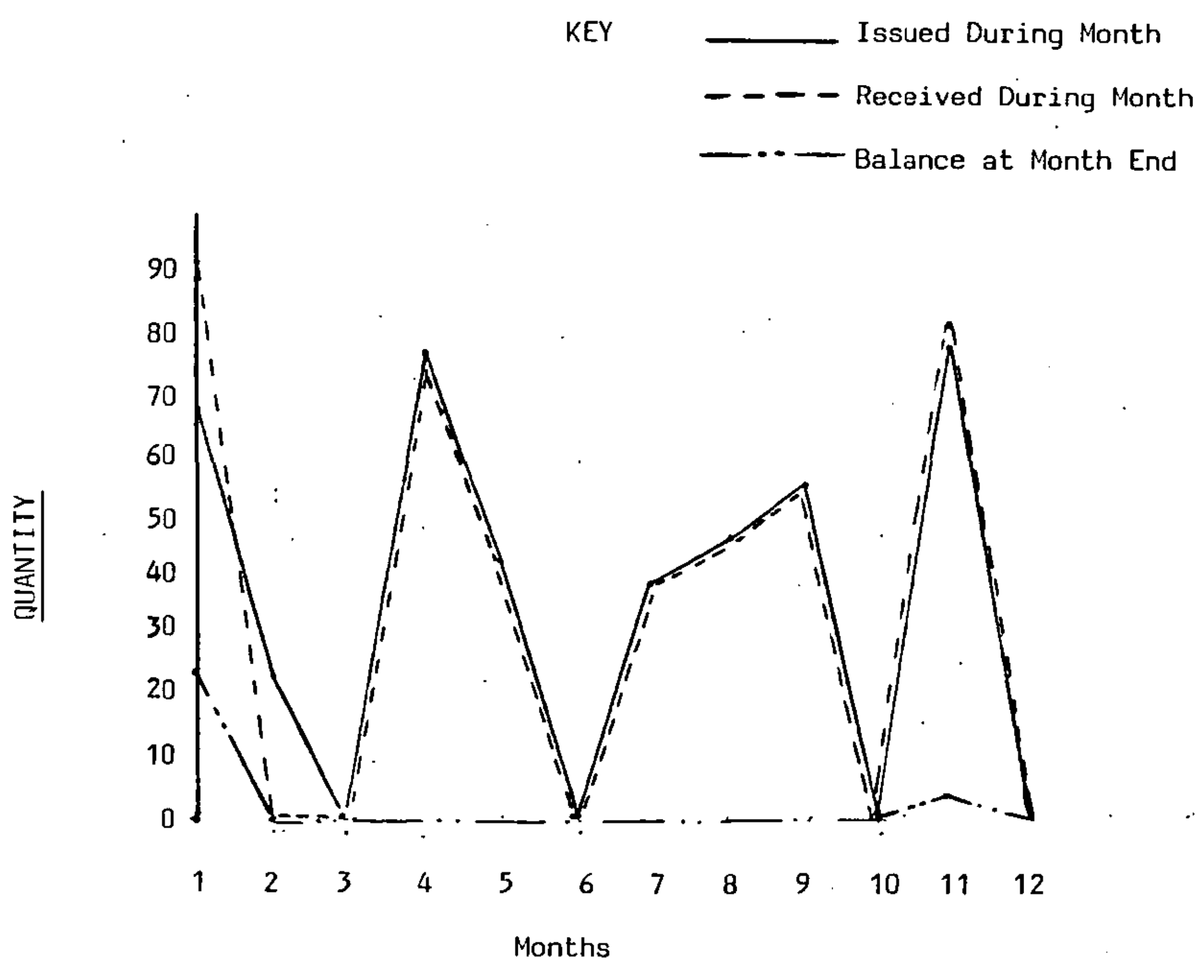
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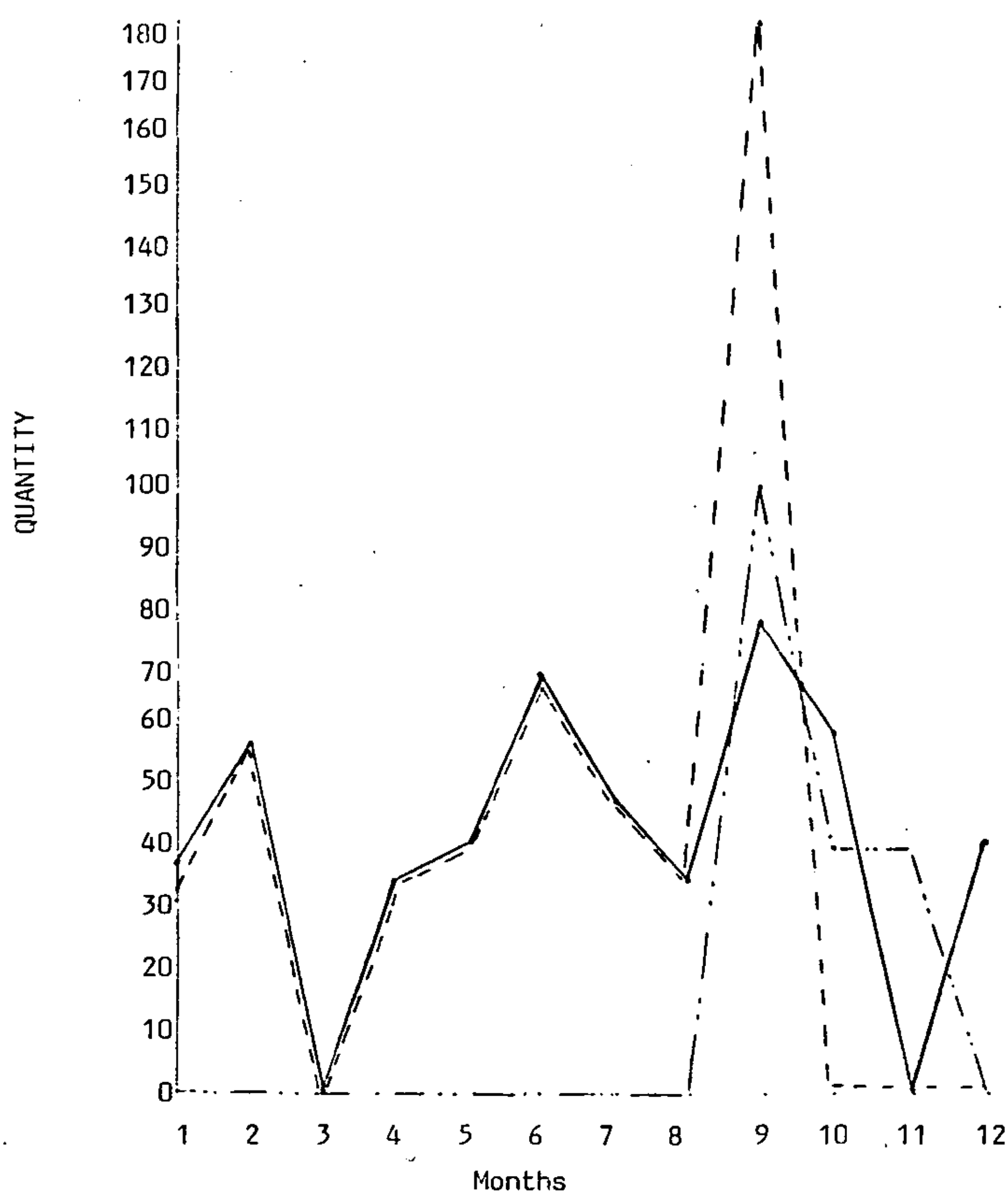
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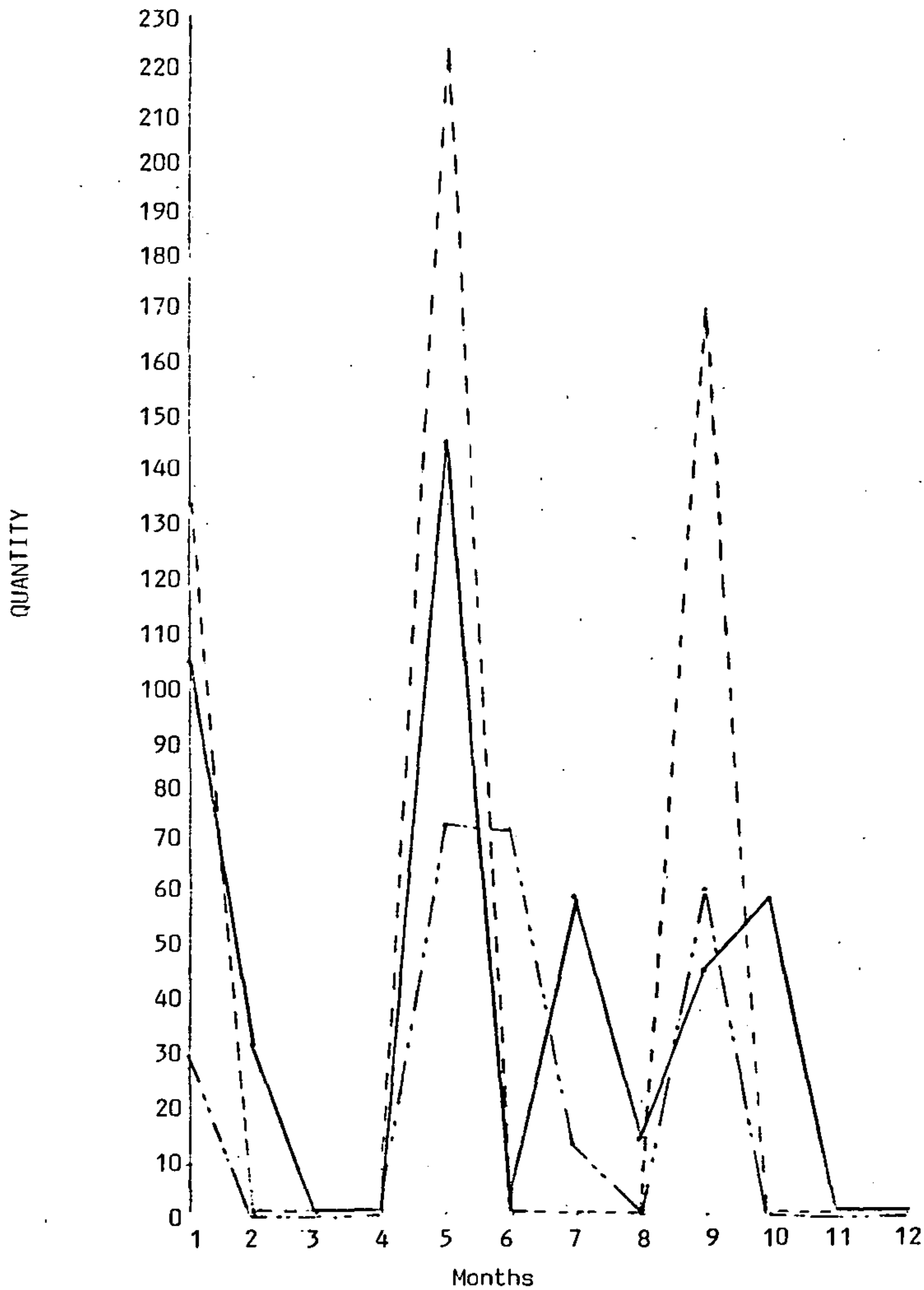
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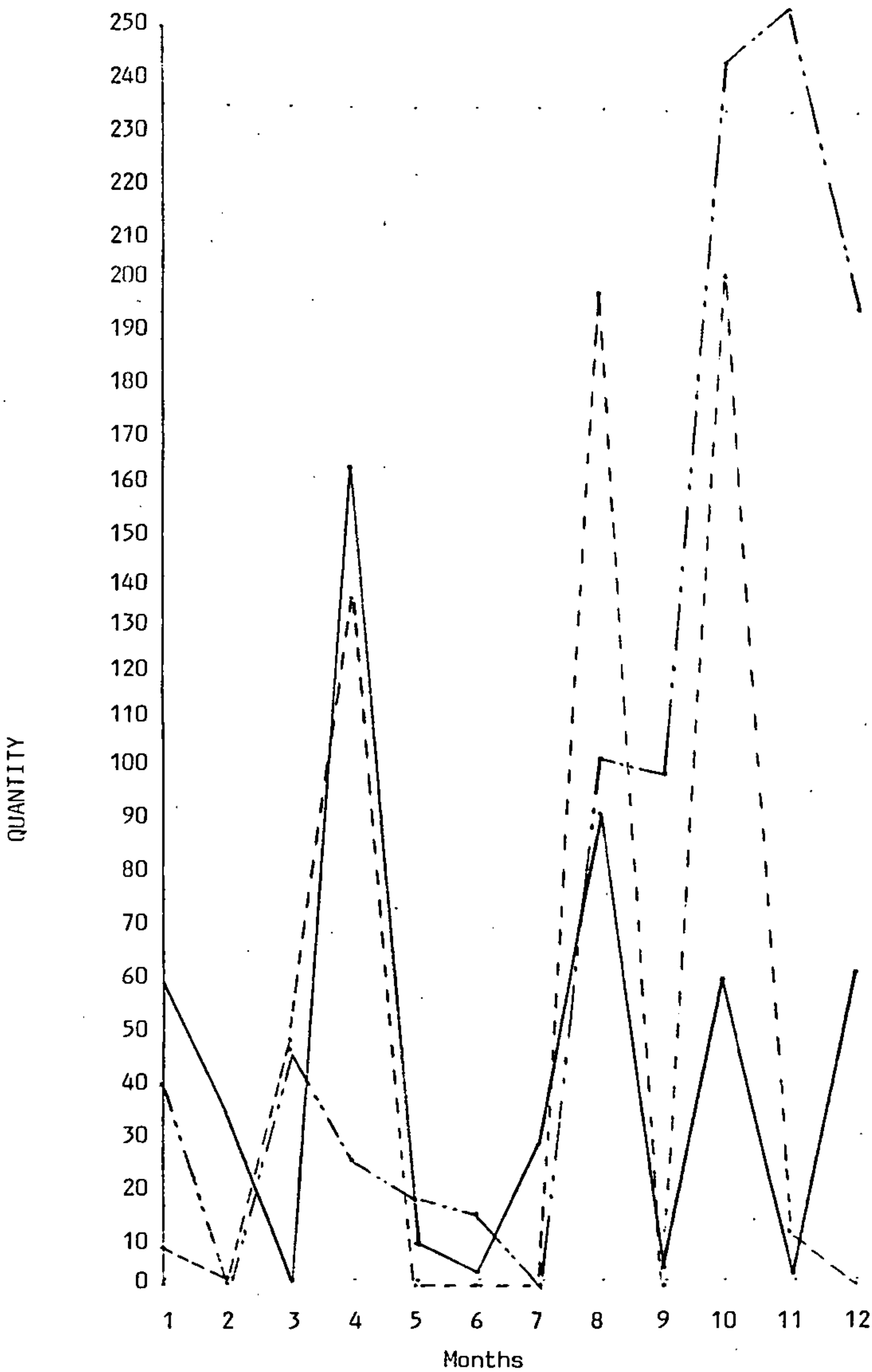
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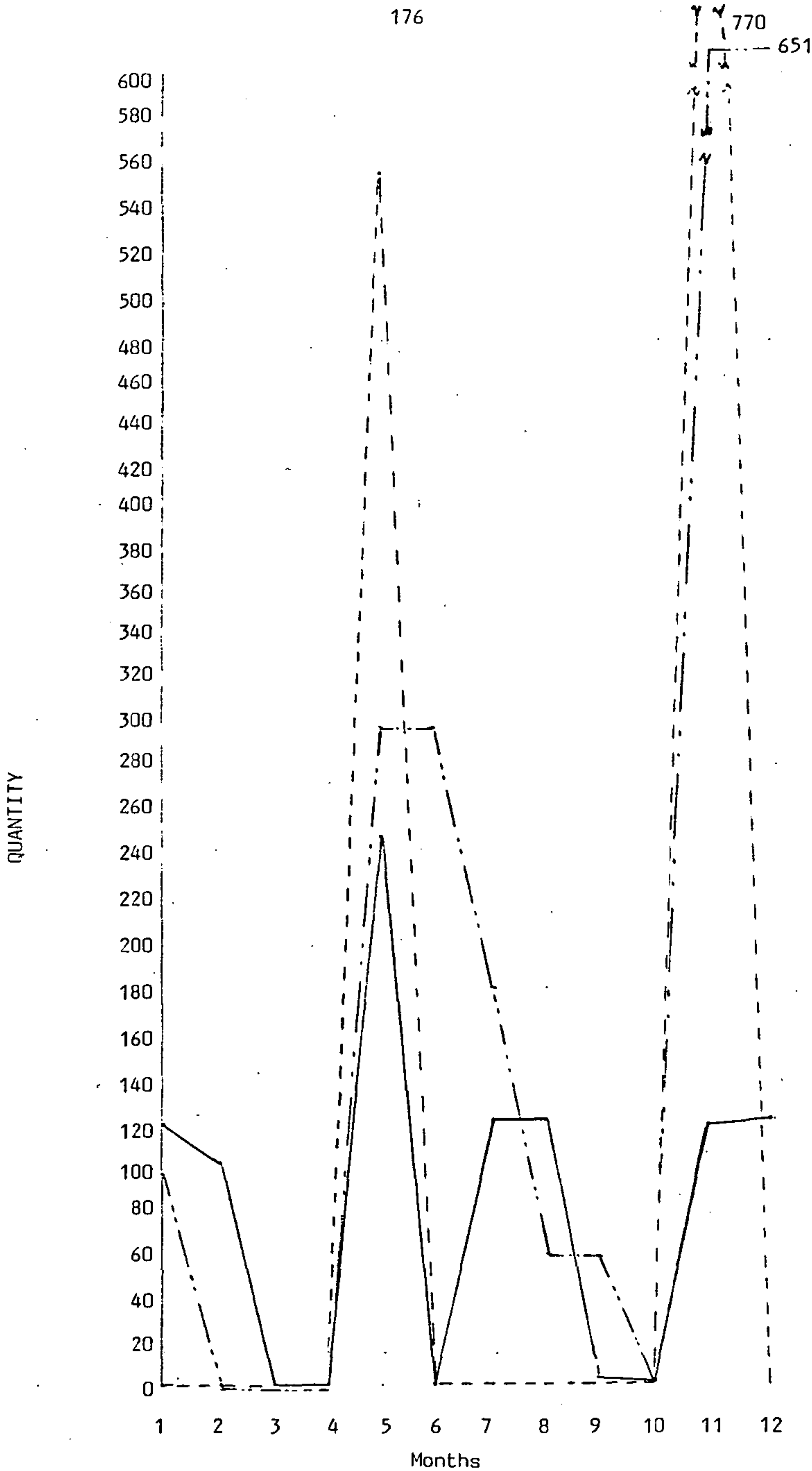
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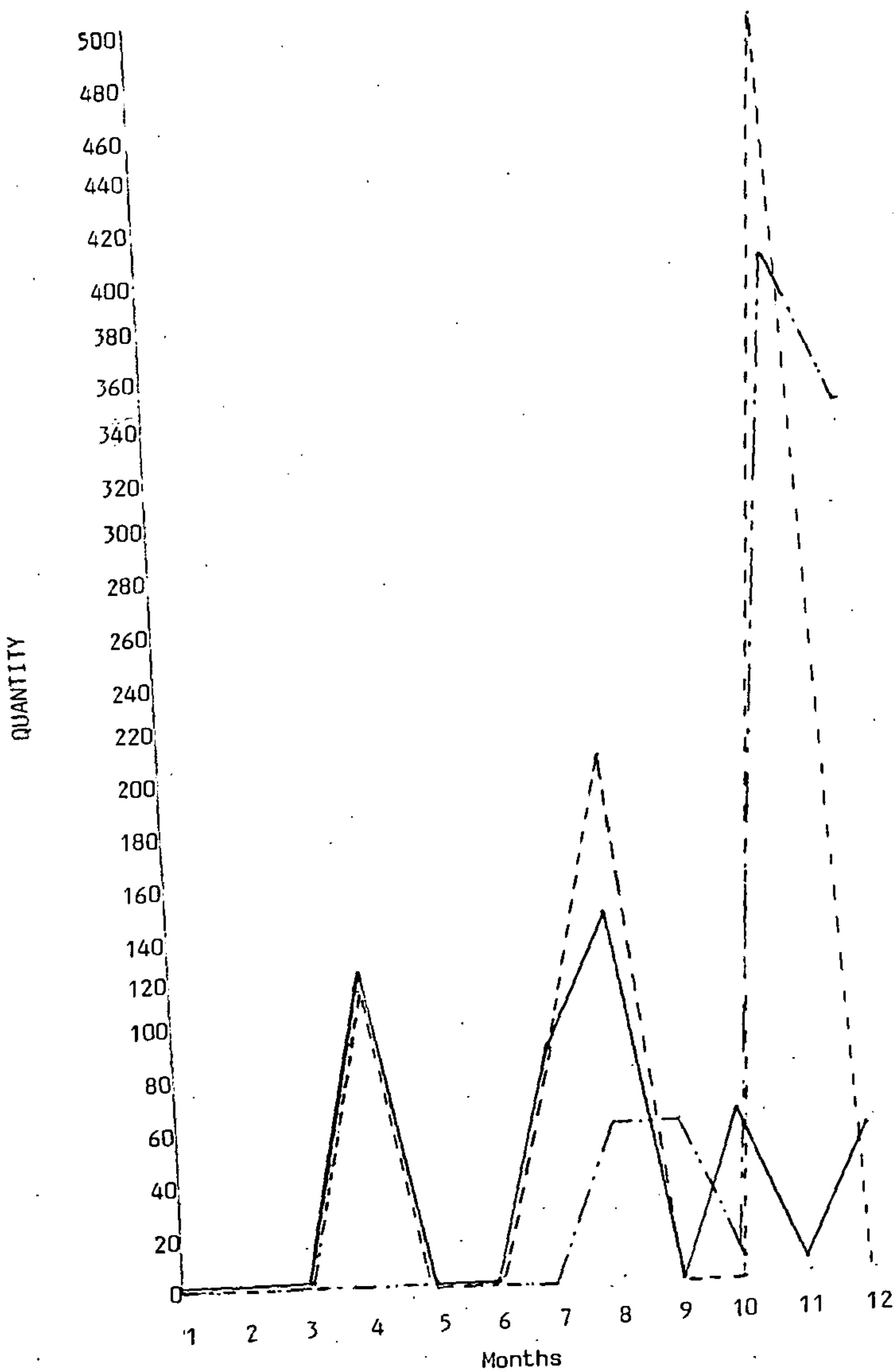
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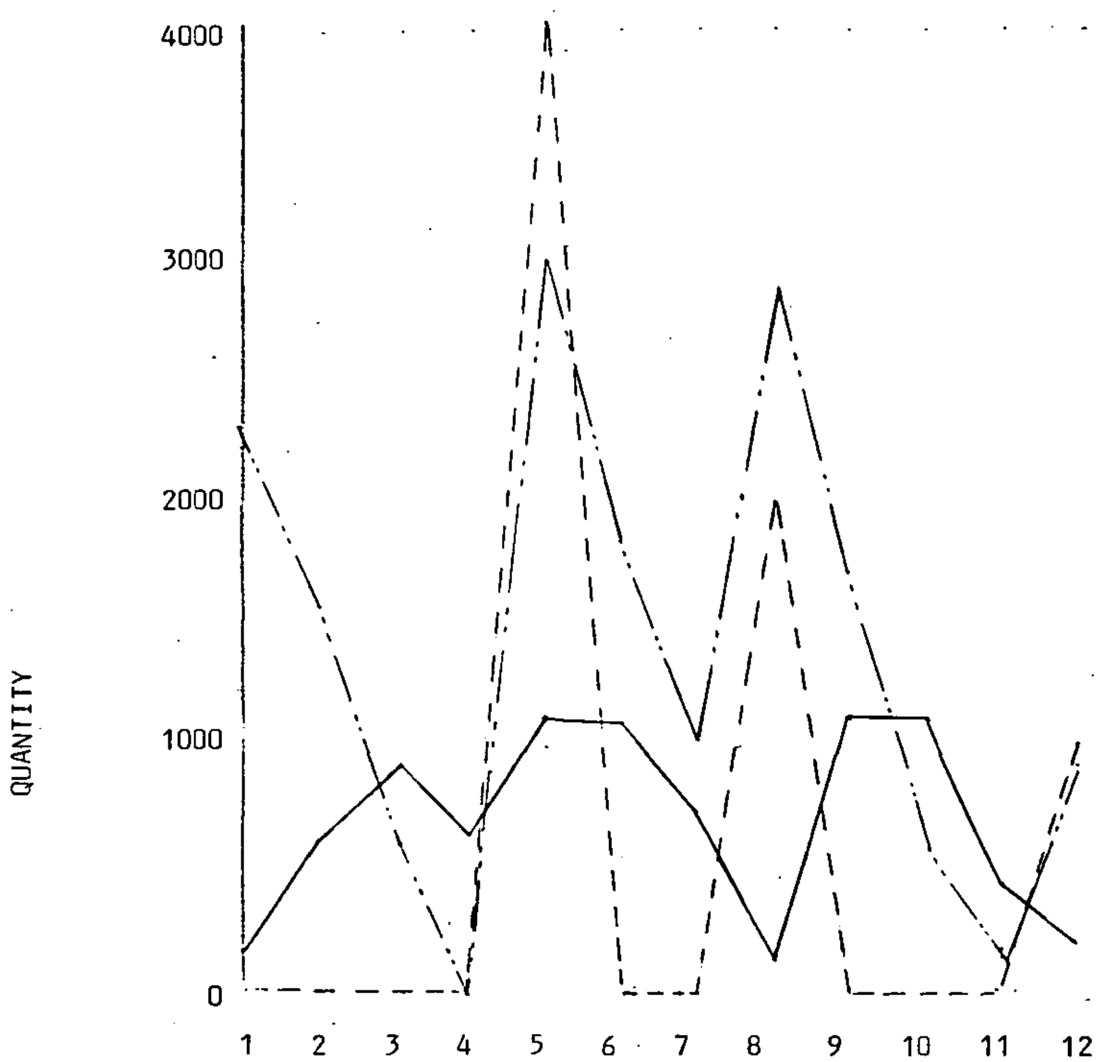

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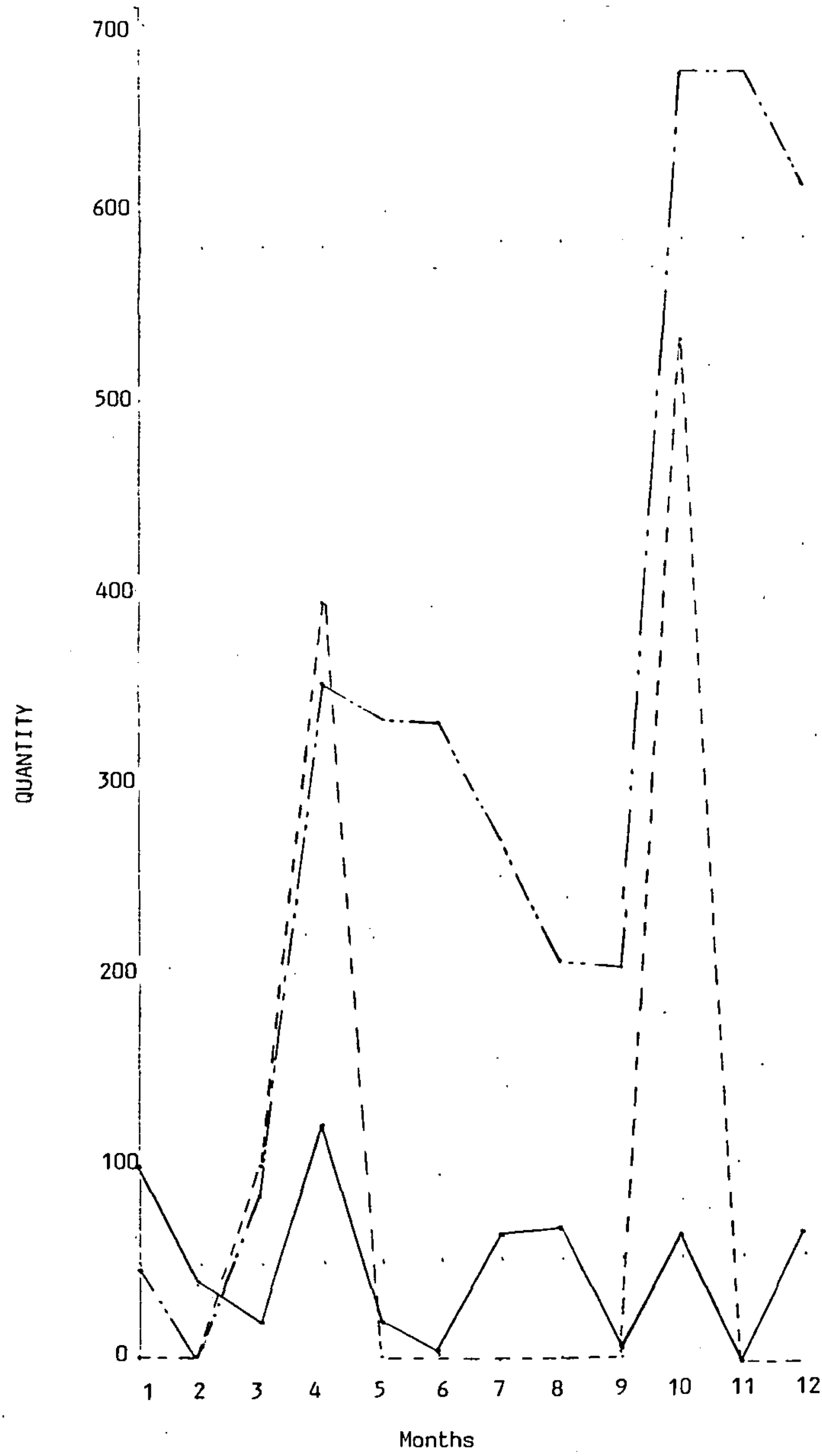
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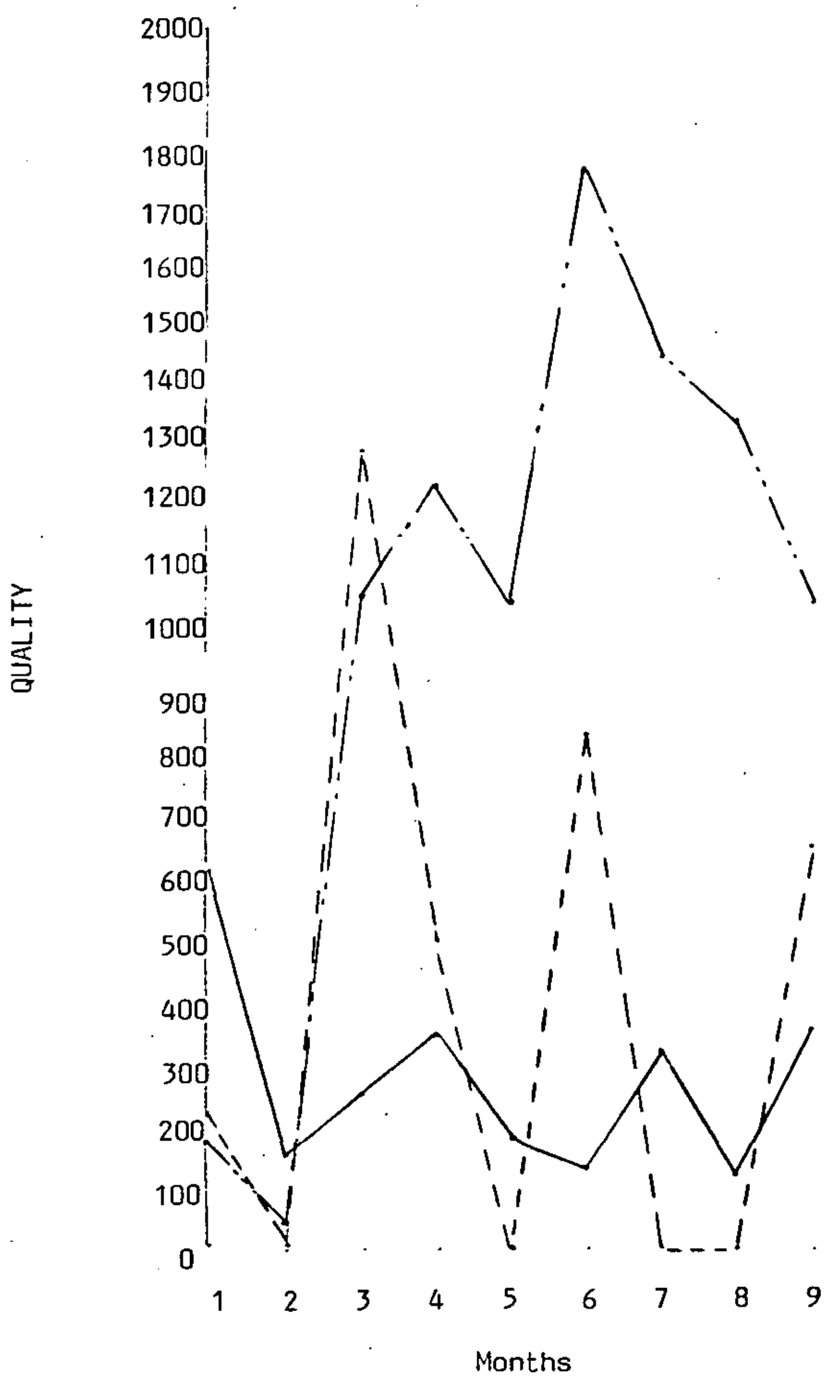
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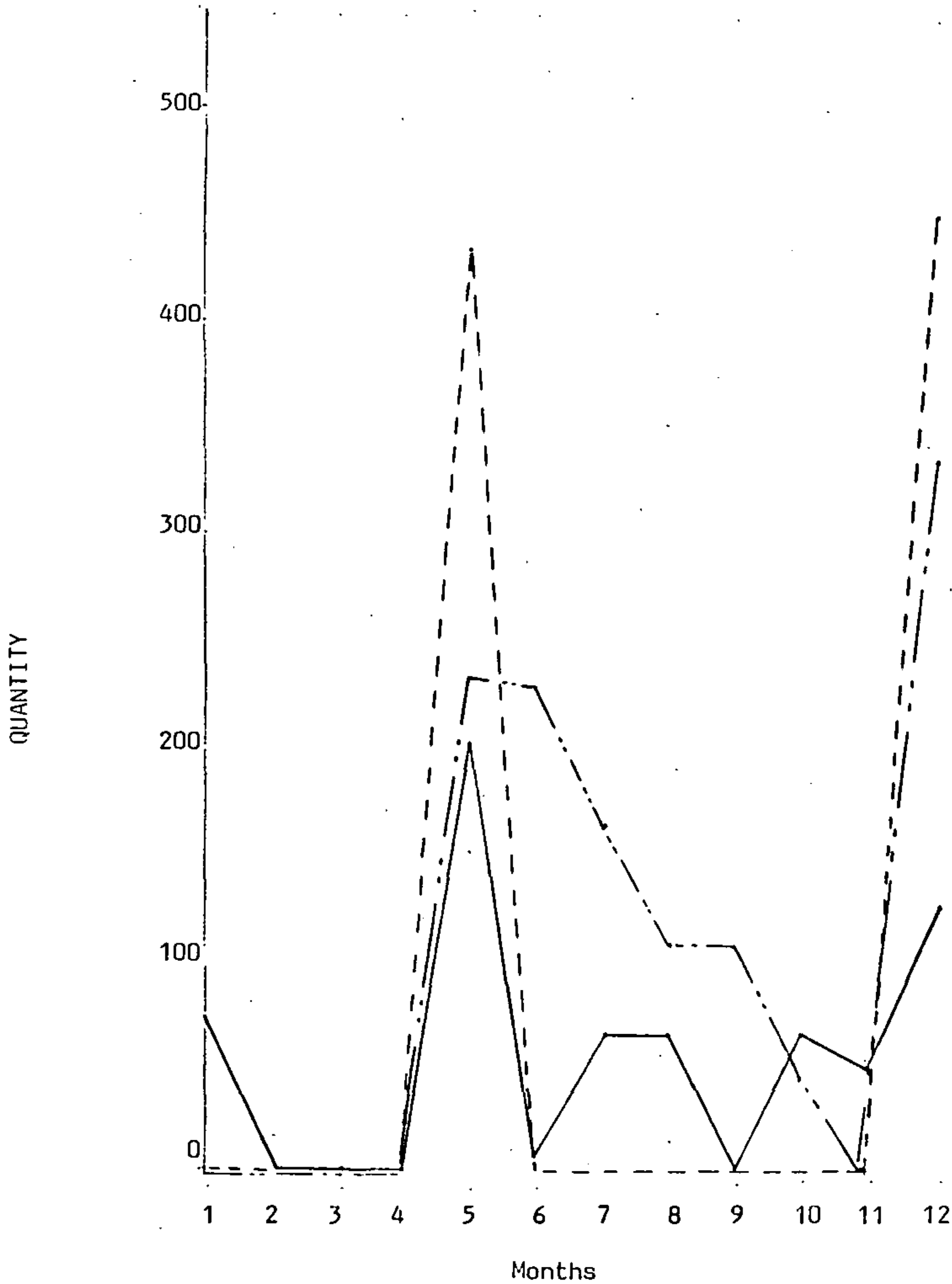
ITEM 10



ITEM 11

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Director and Professor of Management Sciences: J C HIGGINS BSc MA MSc PhD CEng MIEE FBIM

Professor of Operations Management: K G LOCKYER BSc CEng MBIM

THE PRACTICE OF PRODUCTION MANAGEMENT IN THE U.K.

I. I. M. SURVEY - AUTUMN 1980

PRODUCTION PLANNING AND CONTROL

Analysis by size of manufacturing unit

No. of Employees in Unit	No. of Respondents	Percentage of Respondents who state they have: A Production Planning and Control Dept.	A Senior Production Executive Responsible for the Production Planning & Control Dept.	A Computer used by Production Control
Under 50	295	56.9	51.5	19.3
50 - 99	199	76.9	69.3	25.6
100 - 149	204	85.3	77.0	33.8
150 - 249	227	88.1	77.5	43.2
250 - 499	336	89.3	76.5	52.7
500 - 999	286	95.8	78.3	52.2
1000 - 4999	253	95.3	79.8	75.9
5000 - 9999	35	97.1	88.6	91.4
over 10,000	28	96.4	92.9	89.3
Not classified by size	3			
Overall		84.1	73.0	47.1
Totals	1866	1570	1363	879

The above figures were derived from a survey sponsored by the Institution of Industrial Managers and carried out by the Production Management Group of the Management Centre, Bradford. 10,000 members of the I. I. M. were asked in Autumn 1980 to fill in a questionnaire on their work and it is the responses to this request which are here analysed. This sampling frame is likely to give an upward bias towards the reporting of "good" managerial techniques.

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THE PRACTICE OF PRODUCTION MANAGEMENT IN THE U.K.

I. I. M. SURVEY - AUTUMN 1980

PRODUCTION PLANNING AND CONTROL

Analysis by Nationality of Ownership

NATIONALITY OF PRINCIPAL OWNERSHIP	NUMBER OF RESPONDENTS	Percentage of Respondents who state they have: Production Planning and Control Dept.	A Senior Production Executive Responsible for the Production Planning & Control Dept.	A computer used for Production Control
U.K.	1474	82.2	71.8	42.3
U.S.A.	260	94.6	81.5	73.1
E.E.C.	67	92.5	76.1	52.2
Other	61	82.0	68.9	49.2
Not Classified	4			
Overall		84.1	73.1	47.1
Totals	1866	1570	1364	879

The above figures were derived from a survey sponsored by the Institution of Industrial Managers and carried out by the Production Management Group of the Management Centre, Bradford. 10,000 members of the I.I.M. were asked in Autumn 1980 to fill in a questionnaire on their work and it is the responses to this request which are here analysed. This sampling frame is likely to give an upward bias towards the reporting of 'good' managerial techniques.

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THE PRACTICE OF PRODUCTION MANAGEMENT IN THE U.K.

I. I. M. SURVEY - AUTUMN 1980

THE USE OF COMPUTERS FOR PRODUCTION CONTROL

Analysis by size of manufacturing unit

No. of Employees in Unit	No. of Respondents	Percentage of Respondents who stated they use a: Main Frame Computer	Mini Computer	Micro Computer	Total
Under 50	295	11.9	3.1	3.1	18.1
50 - 99	199	17.6	5.5	1.5	24.6
100 - 149	204	21.6	8.8	2.0	32.4
150 - 249	227	26.9	10.6	2.2	39.7
250 - 499	336	41.7	7.1	2.1	50.9
500 - 999	285	48.3	8.0	1.4	57.7
1000 - 4999	253	64.0	6.7	1.2	71.9
5000 - 9999	35	68.6	14.3	0	82.9
over 10,000	28	75.0	7.1	0	82.1
Not classified by size	3				
Overall		35.4	7.1	1.9	44.4
Totals	1866	660	133	35	828

The above figures were derived from a survey sponsored by the Institution of Industrial Managers and carried out by the Production Management Group of the Management Centre, Bradford. 10,000 members of the I. I. M. were asked in Autumn 1980 to fill in a questionnaire on their work and it is the responses to this request which are here analysed. This sampling frame is likely to give an upward bias towards the reporting of "good" managerial techniques.

UNIVERSITY OF BRADFORD

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THE PRACTICE OF PRODUCTION MANAGEMENT IN THE U.K.

I. I. M. SURVEY - AUTUMN 1980

THE USE OF COMPUTERS FOR PRODUCTION PLANNING AND CONTROL

Analysis by Nationality of Ownership

NATIONALITY OF PRINCIPAL OWNERSHIP	NUMBER OF RESPONDENTS	Percentage of Respondents who stated they use a: Main Frame Computer	Mini Computer	Micro Computer	Total
U.K.	1474	30.9	6.9	1.9	39.7
U.S.A.	260	59.2	8.5	2.3	70.0
E.E.C.	67	41.8	4.5	1.5	47.8
Other	61	36.1	11.5	0	47.6
Not Classified	4				
Overall		35.3	7.2	1.9	44.4
Totals	1866	659	134	35	828

The above figures were derived from a survey sponsored by the Institution of Industrial Managers and carried out by the Production Management Group of the Management Centre, Bradford. 10,000 members of the I.I.M. were asked in Autumn 1980 to fill in a questionnaire on their work and it is the responses to this request which are here analysed. This sampling frame is likely to give an upward bias towards the reporting of good managerial techniques.

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THE PRACTICE OF PRODUCTION MANAGEMENT IN THE U.K.

I. I. M. SURVEY - AUTUMN 1980

THE USE OF A COMPUTER

Analysis by size of manufacturing unit

No. of Employees in Unit	No. of Respondents	Percentage of Respondents who state a Computer is used: For Production Control	By first line Supervision	For Stock Control
Under 50	295	19.3	9.5	23.1
50 - 99	199	25.6	8.5	27.1
100 - 149	204	33.8	9.3	38.2
150 - 249	227	43.2	15.0	49.3
250 - 499	336	52.7	18.8	57.1
500 - 999	286	62.2	23.1	64.7
1000 - 4999	253	75.9	24.1	77.9
5000 - 9999	35	91.4	42.9	88.6
over 10,000	28	89.3	42.9	96.4
Not classified by size	3			
Overall		47.1	16.9	50.6
Totals	1866	879	315	944

The above figures were derived from a survey sponsored by the Institution of Industrial Managers and carried out by the Production Management Group of the Management Centre, Bradford. 10,000 members of the I. I. M. were asked in Autumn 1980 to fill in a questionnaire on their work and it is the responses to this request which are here analysed. This sampling frame is likely to give an upward bias towards the reporting of "good" managerial techniques.

41, 43, 47/3

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THE PRACTICE OF PRODUCTION MANAGEMENT IN THE U.K.

I. I. M. SURVEY - AUTUMN 1980

USE OF COMPUTER

Analysis by Nationality of Ownership

NATIONALITY OF PRINCIPAL OWNERSHIP	NUMBER OF RESPONDENTS	Percentage of Respondents who state a Computer is used: for Production Control	by first line supervision	for stock control
U.K.	1474	42.3	14.6	46.4
U.S.A.	260	73.1	29.5	74.6
E.E.C.	67	52.2	19.4	49.3
Other	61	49.2	14.8	50.8
Not Classified	4			
Overall		47.1	16.8	50.5
Totals	1866	879	314	942

The above figures were derived from a survey sponsored by the Institution of Industrial Managers and carried out by the Production Management Group of the Management Centre, Bradford. 10,000 members of the I.I.M. were asked in Autumn 1980 to fill in a questionnaire on their work and it is the responses to this request which are here analysed. This sampling frame is likely to give an upward bias towards the reporting of good managerial techniques.

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THE PRACTICE OF PRODUCTION MANAGEMENT IN THE U.K.

I. I. M. SURVEY - AUTUMN 1980

STOCK CONTROL

Analysis by size of manufacturing unit

No. of Employees in Unit	No. of Respondents	Percentage of Respondents who state they use: An Explicit Technique to Control Stock Levels of: Purchased Material	Work-in-Progress	Products for Sale	A Computer for Stock Control
Under 50	295	63.4	54.9	57.3	23.1
50 - 99	199	71.9	57.8	59.8	27.1
100 - 149	204	82.8	63.7	72.1	38.2
150 - 249	227	80.6	67.4	69.6	49.3
250 - 499	336	76.5	62.5	68.8	57.1
500 - 999	286	88.8	72.7	78.0	64.7
1000 - 4999	253	84.2	71.5	74.3	77.9
5000 - 9999	35	91.4	74.3	77.1	88.6
over 10,000	28	96.4	78.6	75.0	96.4
Not classified by size	3				
Overall		78.5	64.7	68.8	50.6
Totals	1866	1465	1207	1283	944

The above figures were derived from a survey sponsored by the Institution of Industrial Managers and carried out by the Production Management Group of the Management Centre, Bradford. 10,000 members of the I. I. M. were asked in Autumn 1980 to fill in a questionnaire on their work and it is the responses to this request which are here analysed. This sampling frame is likely to give an upward bias towards the reporting of "good" managerial techniques.

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THE PRACTICE OF PRODUCTION MANAGEMENT IN THE U.K.

I. I. M. SURVEY - AUTUMN 1980

STOCK CONTROL

Analysis by Nationality of Ownership

NATIONALITY OF PRINCIPAL OWNERSHIP	NUMBER OF RESPONDENTS	Percentage of Respondents who state they use: An Explicit Technique to Control Stock Levels of: Purchased Material	Work-in-Progress	Products for Sale	A Computer for Stock Control
U.K.	1474	76.6	63.0	67.0	46.4
U.S.A.	260	90.0	75.4	81.9	74.6
E.E.C.	67	83.6	70.1	70.1	49.3
Other	61	73.8	60.7	62.3	50.8
Not Classified	4				
Overall		78.5	64.7	68.8	50.5
Totals	1866	1464	1208	1284	942

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B/39,46,53,54,36/1

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THE PRACTICE OF PRODUCTION MANAGEMENT IN THE U.K.

I. I. M. SURVEY - AUTUMN 1980

STOCK CONTROL (USAGE)

Analysis by Size of Manufacturing Unit

NUMBER OF EMPLOYEES IN UNIT	NUMBER OF RESPONDENTS	Percentage of Respondents who state that they use: Economic Order Quantity	M.R.P.	Re-Order Cycle	Re-Order Level	Coverage Analysis
Under 50	295	51.9	60.7	44.1	57.3	8.8
50 - 99	199	51.8	68.3	52.3	74.4	5.0
100 - 149	204	58.8	69.1	58.8	70.6	5.9
150 - 249	227	66.1	71.8	64.8	78.0	4.8
250 - 499	336	58.0	71.1	57.4	74.4	9.8
500 - 999	286	52.7	71.7	59.4	72.7	8.4
1000 - 4999	253	48.3	56.6	53.4	65.6	7.1
5000 - 9999	35	51.4	71.4	42.9	57.1	11.4
Over 10,000	28	35.7	64.3	50.0	60.7	14.3
Not Classified	3					
Overall		57.0	68.0	55.1	69.6	7.6
Totals	1,866	1,064	1,268	1,028	1,299	142

The above figures were derived from a survey sponsored by the Institution of Industrial Managers and carried out by the Production Management Group of the Management Centre, Bradford. 10,000 members of the I. I. M. were asked in Autumn 1980 to fill in a questionnaire on their work and it is the responses to this request which are here analysed. This sampling frame is likely to give an upward bias towards the reporting of "good" managerial techniques.

B/39,46,53,54,36/3

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I. I. M. SURVEY - AUTUMN 1980

STOCK CONTROL (USAGE)

Analysis by Ownership

NATIONALITY OF PRINCIPAL OWNERSHIP	NUMBER OF RESPONDENTS	Percentage of Respondents who state that they use: E.O.Q.*	M.R.P.	Re-Order Cycle	Re-Order Level	Coverage Analysis
U. K.	1474	54.8	66.8	53.5	68.7	7.6
U. S. A.	260	65.0	73.5	63.8	73.1	6.9
E. E. C.	67	67.2	71.6	61.2	73.1	9.0
OTHER	61	65.6	68.9	52.5	75.4	8.2
NOT CLASSIFIED	4					
OVERALL		56.9	67.8	55.1	69.6	7.6
TOTALS	1,866	1,062	1,266	1,028	1,298	142

* E.O.Q. = Economic Order Quantity

The above figures were derived from a survey sponsored by the Institution of Industrial Managers and carried out by the Production Management Group of the Management Centre, Bradford. 10,000 members of the I. I. M. were asked in Autumn 1980 to fill in a questionnaire on their work and it is the responses to this request which are here analysed. This sampling frame is likely to give an upward bias towards the reporting of "good" managerial techniques.

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THE PRACTICE OF PRODUCTION MANAGEMENT IN THE U.K.

I. I. M. SURVEY - AUTUMN 1980

MATHEMATICAL TECHNIQUES (USAGE)

Analysis by Size of Manufacturing Unit

NUMBER OF EMPLOYEES IN UNIT	NUMBER OF RESPONDENTS	Percentage of Respondents who state that they use:					
		Branch and Bound	Critical Path Analysis	Decision Networks	Exponential Smoothing	Line of Balance	Linear Programming
Under 50	295	2.4	37.6	24.4	10.8	13.2	12.9
50 - 99	199	1.0	39.2	22.1	10.1	11.6	14.1
100 - 149	204	1.4	44.1	27.0	17.2	17.2	13.7
150 - 249	227	0.4	50.7	25.1	13.7	10.1	17.2
250 - 499	336	1.2	57.1	29.2	20.8	15.5	18.8
500 - 999	286	0.3	59.1	34.6	24.8	17.5	27.3
1000 - 4999	253	0.4	68.4	43.1	22.9	18.6	27.7
5000 - 9999	35	0	60.0	57.1	21.4	37.1	34.3
Over 10,000	28	3.6	64.3	53.6	35.7	25.0	42.9
Not Classified	3						
Overall		1.1	51.8	30.5	18.9	15.5	19.7
Totals	1,866	20	967	569	351	289	368

The above figures were derived from a survey sponsored by the Institution of Industrial Managers and carried out by the Production Management Group of the Management Centre, Bradford. 10,000 members of the I. I. M. were asked in Autumn 1980 to fill in a questionnaire on their work and it is the responses to this request which are here analysed. This sampling frame is likely to give an upward bias towards the reporting of "good" managerial techniques.

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B/32,37,38,40,43/44/3

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THE PRACTICE OF PRODUCTION MANAGEMENT IN THE U.K.

I. I. M. SURVEY - AUTUMN 1980

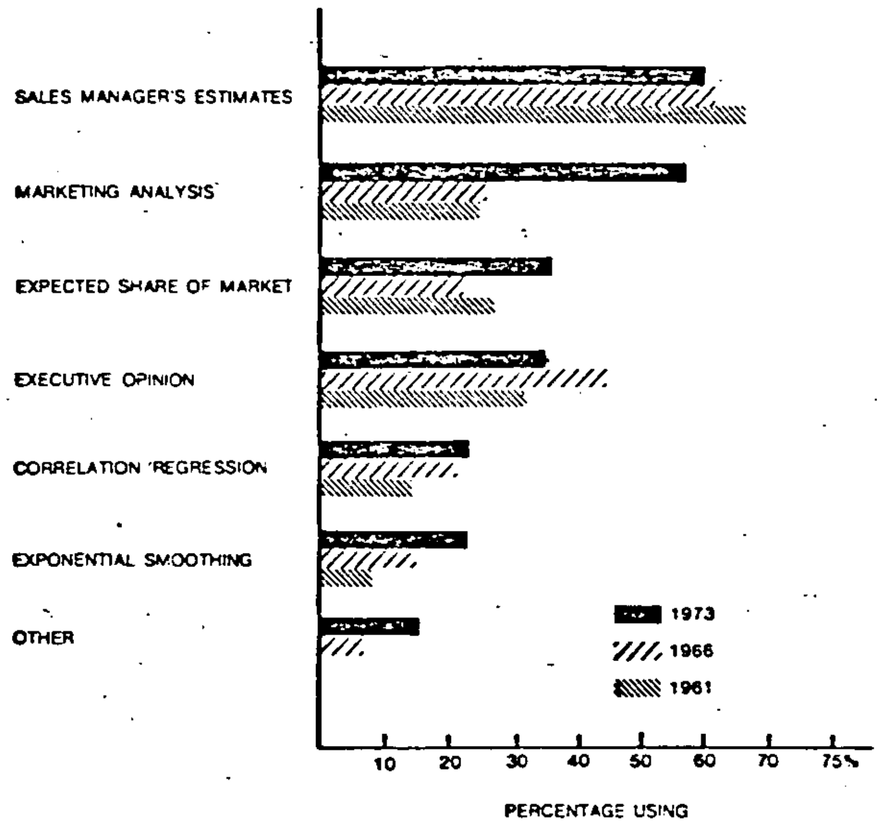
MATHEMATICAL TECHNIQUES (USAGE)

Analysis by Ownership

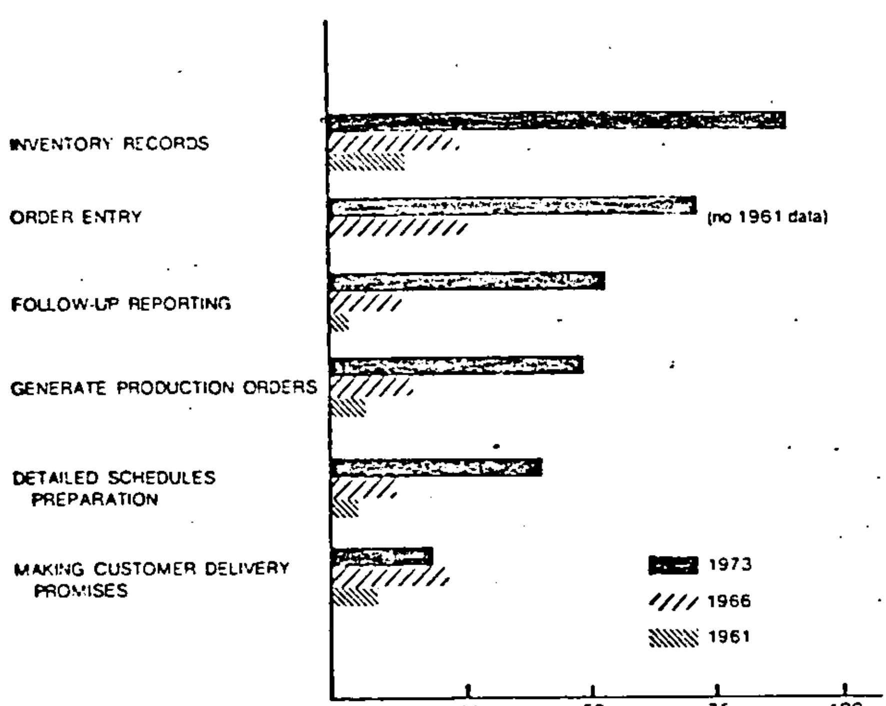
NATIONALITY OF PRINCIPAL OWNERSHIP	NUMBER OF RESPONDENTS	Percentage of Respondents who state that they use: Branch and Bound	Critical Path Analysis	Decision Networks	Exponential Smoothing	Line of Balance	L.P.*
U. K.	1474	1.0	49.6	28.5	16.6	14.4	19.2
U. S. A.	260	1.5	61.5	36.9	31.2	23.1	23.1
E. E. C.	67	0	61.2	38.8	17.9	13.4	19.4
OTHER	61	1.6	55.7	41.0	21.3	13.1	16.4
NOT CLASSIFIED	4						
OVERALL		1.1	51.8	30.4	18.8	15.5	19.6
TOTALS	1,866	20	966	567	351	289	366

*L.P. = Linear Programming

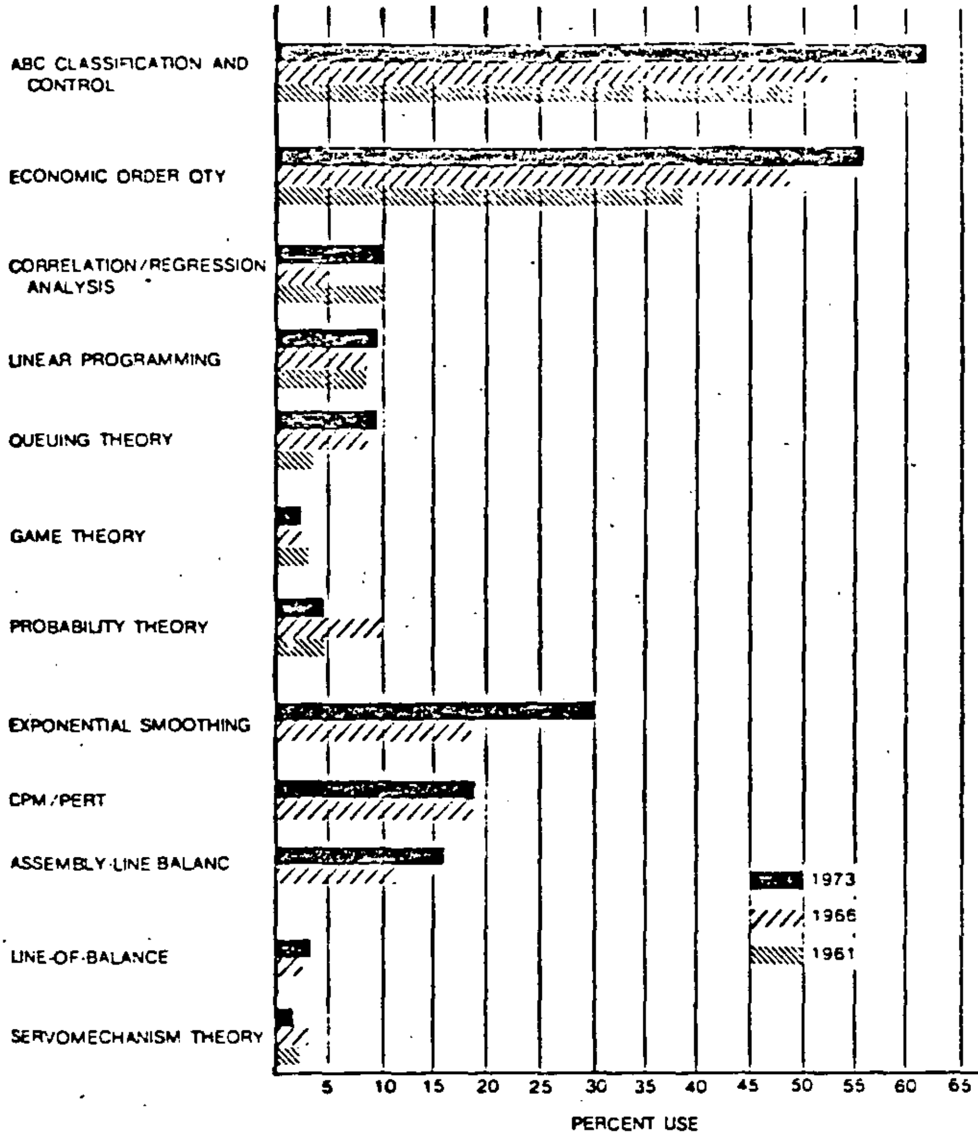
The above figures were derived from a survey sponsored by the Institution of Industrial Managers and carried out by the Production Management Group of the Management Centre, Bradford. 10,000 members of the I. I. M. were asked in Autumn 1980 to fill in a questionnaire on their work and it is the responses to this request which are here analysed. This sampling frame is likely to give an upward bias towards the reporting of "good" managerial techniques.



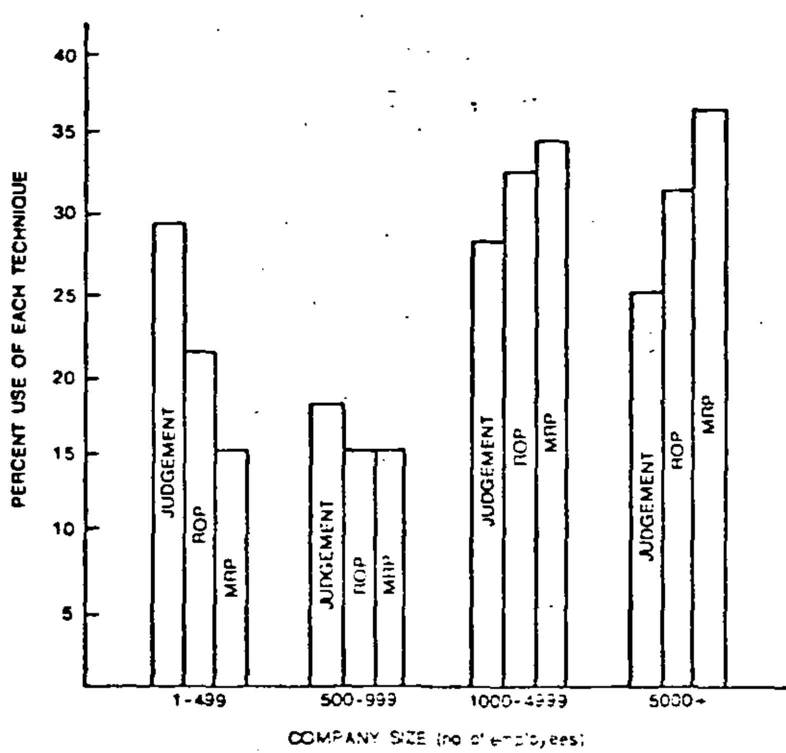
Procedures used in making sales forecasts



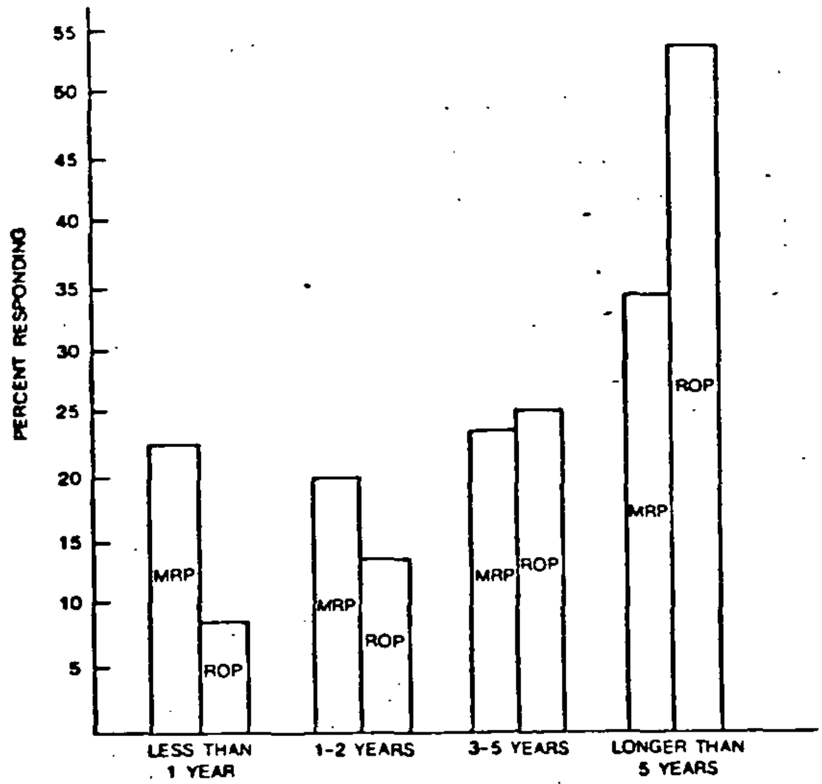
Use of the computer in PIC



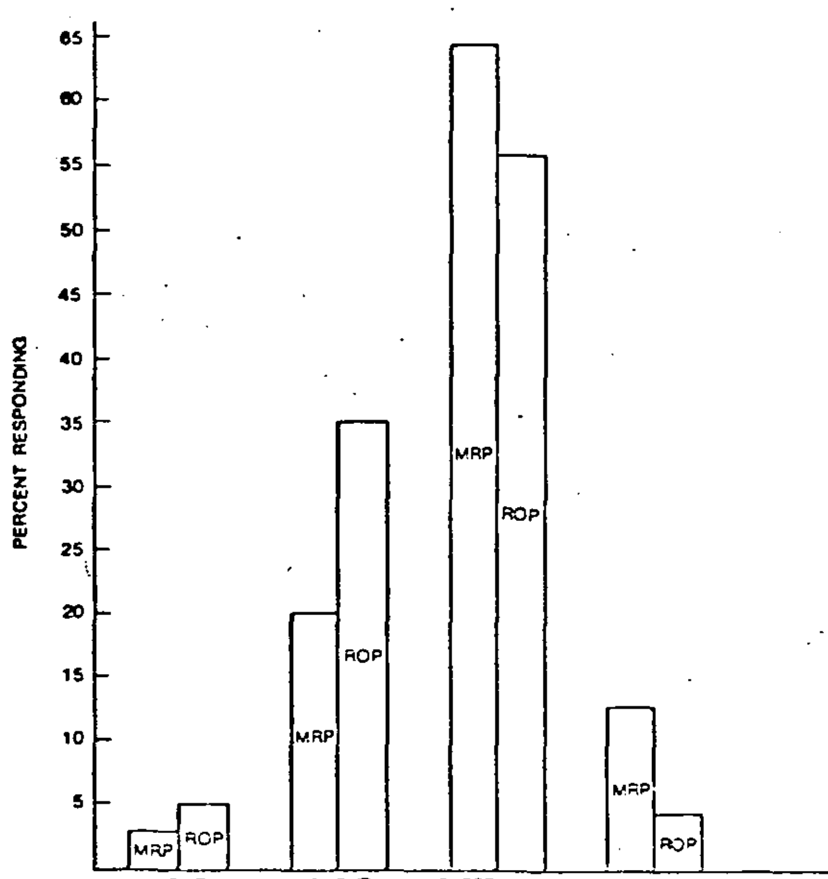
Current and past use of scientific techniques



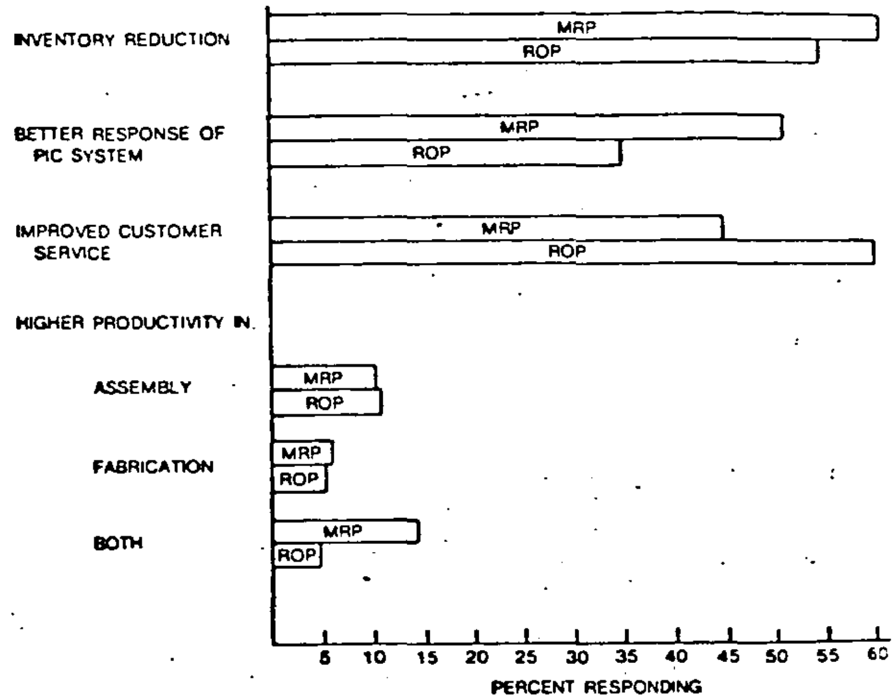
Use of inventory technique vs. company size



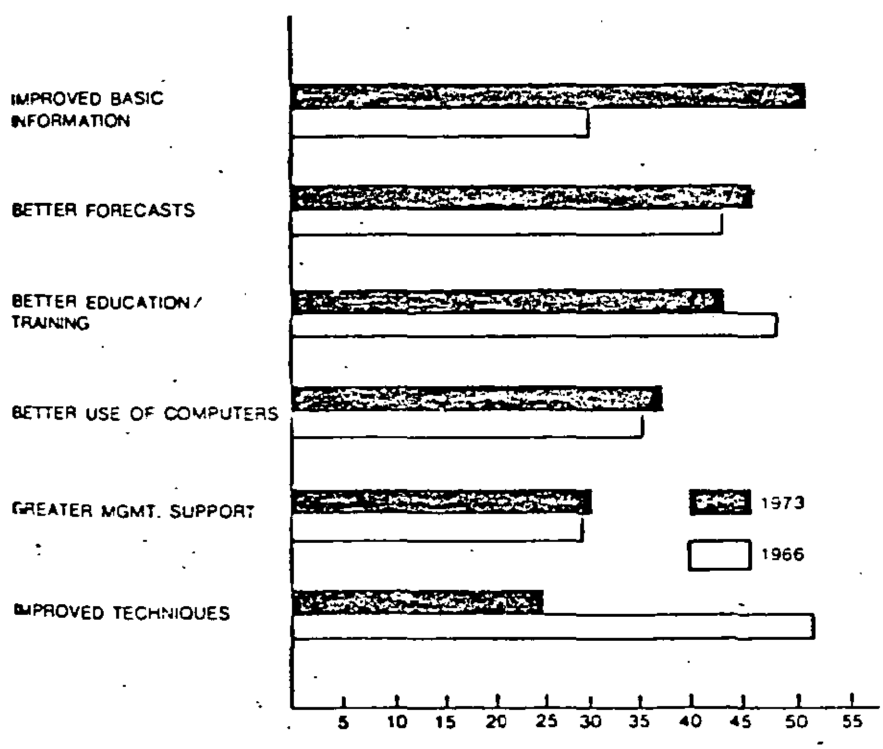
Length of time used, MRP vs. ROP



Degree of benefits obtained, MRP vs. ROP



Nature of benefits obtained, MRP vs. ROP



What the respondents felt is needed to made PIC more effective

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